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ANNUAL RENEWABLE ENERGY TECHNOLOGY REVIEW

Progress Through 1984

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PREFACE

PREFACE

Renewable energy sources are increasingly being recognized for their important and growing contribution to energy supply. The U.S. Department of Energy calculated that 9% of the nation's energy (14% of U.S. electricity production) came from renewable resources in 1984. Other sources estimate that renewable energy now supplies more than 10%. Despite fluctuations in the energy market, such as the oil price collapse in 1986, it is clear that renewable energy is here to stay.

Renewable energy encompasses a variety of resources: solar, wind, hydro, biomass, geothermal and the oceans. The technologies used to harness these energy sources are at varying levels of sophistication and market competitiveness, and are used for a variety of end-use applications. The Annual Renewable Energy Technology Review is organized in such a fashion that it serves as a comprehensive source document on each of the technologies, yet can also be used to easily identify any of the technology's current contribution to the energy supply and serves as a baseline to monitor their progress over time.

The Renewable Energy Institute has a seen a growing need to provide a central source of information on the full range of renewable energy technologies. Inquiries from federal and state governments, colleges and universities, renewable energy companies, foreign companies and governments, journalists, and the general public have revealed that such an information source was sorely lacking. National energy statistics generally identify only the "tip of the iceberg" by surveying traditional supply sources (e.g. electric utilities) and group the renewable energy contribution into the "other" category. Because of their decentralized application, the direct contribution of these technologies and their displacement of conventional energy sources are often overlooked.

The Annual Renewable Energy Technology Review: Progress Through 1984 marks the second effort by the Renewable Energy Institute to quantify the contribution of renewable energy. The publication has been greatly expanded from the previous edition (Progress Though 1983). Information on total resource availability, international activities, and state government incentives has been added. Also, sections which appeared in the previous edition on technology status, industry status, and market status have been enhanced to provide readers with vital information for evaluating the status and prospects of each technology.

The compilation of information contained in this document has required an extensive effort due to the lack of a centralized collection and dissemination mechanism for this type of information. While REI has made every effort to assure the accuracy and completeness of the data, it is important to emphasize that the information in this publication is not the result of original research by the Institute. The information comes from a wide variety of published documents, and from individuals and organizations specializing in specific technologies or applications. Each chapter of the report has been reviewed and edited by numerous individuals and organizations recognized for their knowledge on the subject.

In the twelve years since the first oil shock, remarkable development of the renewable energy technologies has occurred. Renewable energy has made significant inroads into all end-use sectors: residential, commercial, industrial, transportation, and utilities. Specialized market niches, continuous strides in technological development, and experience and information on operating systems ensure the presence of renewable energy in the future. The dramatic drop in oil prices experienced in early 1986 will, most likely, slow but not end the commercialization of these technologies. The momentum achieved by renewable energy, largely over the past decade, is likely to continue at varying levels as the U.S. and the rest of the world move to what the U.S. Department of Energy's current National Energy Policy Plan (NEPP V) describes as "the eventual transition toward renewable energy and alternative fuels." The Annual Renewable Energy Technology Review will continue to provide regularly updated information on the commercial and technological status of the renewable energy technologies as movement is made in this direction.

Chapter 1

U.S. ENERGY OVERVIEW FOR 1984

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U.S. ENERGY OVERVIEW FOR 1984

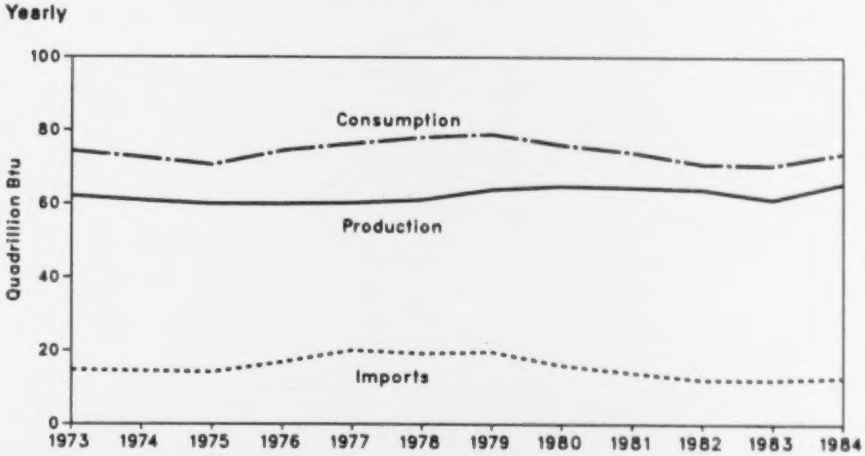
The U.S. is blessed with a diverse energy resource base including substantial domestic supplies of fossil fuels (oil, natural gas and coal), uranium ore for nuclear power, hydroelectric power and other renewable energy sources. The energy picture in 1984 was marked by a reversal in recent trend lines, resulting in a return to growth in supply and consumption of energy. As the economy revitalized and OPEC's control over world oil supplies and prices weakened, the U.S. government decreased its presence in the energy sector, in terms of regulation and development of new energy technologies, and Americans largely forgot the energy crisis of the 1970s.

1984 represented the first year since 1979 that energy production, consumption and imports increased in the U.S. (see FIGURE 1-1). Energy production reached a record high of 65.5 quadrillion BTUs (quads), an increase of 7% over 1983. In fact, the 4.3 quad increase marked the largest annual increase ever recorded. Energy consumption in the U.S. totaled 73.7 quads, a 4.6 % increase from 1983. On a per capita basis energy consumption rose for the first time since 1978. This increased consumption occurred in all sectors (see FIGURE 1-2). Imports also followed the trend totaling 12.7 quads, 5.7% above the previous year. Exports of energy, primarily coal and crude oil, amounted to 3.82 quads up from 3.72 quads in 1983 (see TABLE 1-1).

U.S. ENERGY OVERVIEW FOR 1984

FIGURE 1-1

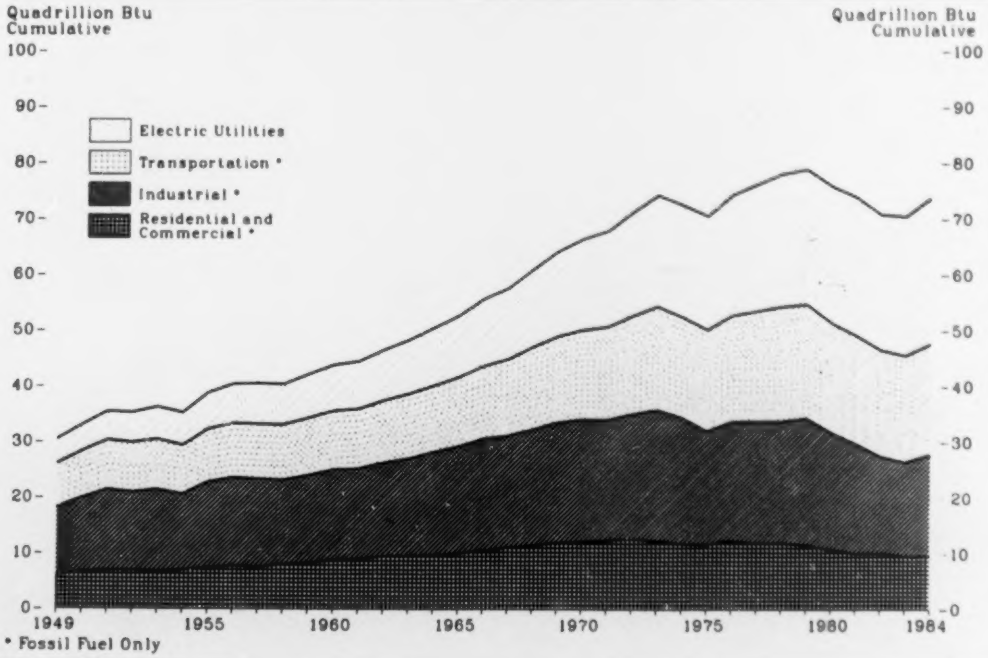
U.S. ANNUAL ENERGY SUMMARY, 1973-1984



Source: Monthly Energy Review. Energy Information Administration, U.S. Department of Energy, December 1984, p. 6.

FIGURE 1-2

CONSUMPTION OF ENERGY BY END-USE SECTOR, 1949-1984



Source: Annual Energy Review 1984. Energy Information Administration, U.S. Department of Energy (DOE/EIA-0384[84]), April 1985, p. 10.

U.S. ENERGY OVERVIEW FOR 1984

TABLE 1-1

ENERGY SUPPLY AND DISPOSITION, 1960, 1970, AND 1973-84

(Quadrillion BTUs)

Activity and Energy Source	1960	1970	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984[1]
Supply														
Production														
Crude Oil and Lease Condensate	14.93	20.40	19.49	18.57	17.73	17.26	17.45	18.43	18.10	18.25	18.15	18.31	18.39	18.59
Natural Gas Plant Liquids	1.46	2.51	2.57	2.47	2.37	2.33	2.33	2.25	2.29	2.25	2.31	2.19	2.18	2.37
Natural Gas[2]	12.66	21.67	22.19	21.21	19.64	19.48	19.57	19.49	20.08	19.91	19.70	18.25	16.53	17.75
Coal	10.83	14.61	14.00	14.08	15.00	15.66	15.76	14.91	17.55	18.60	18.38	18.64	17.25	19.70
Nuclear Power	0.01	0.24	0.91	1.27	1.90	2.11	2.70	3.02	2.78	2.74	3.01	3.13	3.20	3.55
Hydroelectric Power	1.61	2.63	2.86	3.18	3.15	2.98	2.33	2.94	2.93	2.90	2.76	3.26	3.50	3.39
Other[3]	([11])	0.02	0.05	0.06	0.07	0.08	0.08	0.07	0.09	0.11	0.13	0.11	0.13	0.17
Total Production	41.50	62.08	62.07	60.84	59.87	59.90	60.22	61.11	63.81	64.76	64.42	63.89	61.20	65.51
Imports														
Crude Oil[4]	2.20	2.81	6.89	7.40	8.72	11.24	14.03	13.46	13.83	11.19	9.34	7.42	7.08	7.25
Petroleum Products[5]	1.80	4.66	6.58	5.73	4.23	4.43	4.73	4.36	4.11	3.46	3.30	3.36	3.57	4.10
Natural Gas	0.16	0.85	1.06	0.99	0.98	0.99	1.04	0.99	1.30	1.01	0.92	0.95	0.94	0.88
Other[6]	0.07	0.07	0.20	0.30	0.19	0.18	0.30	0.44	0.38	0.31	0.42	0.36	0.44	0.48
Total Imports	4.23	8.39	14.73	14.41	14.11	16.84	20.09	19.25	19.62	15.97	13.97	12.09	12.03	12.71
Adjustments[7]	-0.43	-1.37	-0.46	-0.48	-1.07	-0.18	-1.95	-0.34	-1.66	-1.05	-0.08	-0.51	1.00	-0.68
Total Supply	45.30	69.10	76.34	74.77	72.91	76.55	78.36	80.02	81.77	79.68	78.32	75.47	74.22	77.54
Disposition														
Exports														
Coal	1.02	1.94	1.43	1.62	1.76	1.60	1.44	1.08	1.75	2.42	2.94	2.79	2.04	2.15
Crude Oil and Petroleum Products	0.43	0.55	0.49	0.46	0.44	0.47	0.51	0.77	1.00	1.16	1.26	1.73	1.57	1.55
Other[8]	0.03	0.18	0.14	0.14	0.16	0.12	0.12	0.09	0.11	0.14	0.12	0.11	0.11	0.12
Total Exports	1.48	2.66	2.05	2.22	2.36	2.19	2.07	1.93	2.87	3.72	4.33	4.63	3.72	3.82
Consumption														
Petroleum Products[9]	19.92	29.52	34.84	33.45	32.73	35.17	37.12	37.97	37.12	34.20	31.93	30.23	30.05	31.00
Natural Gas	12.39	21.79	22.51	21.73	19.95	20.35	19.93	20.00	20.67	20.39	19.93	18.51	17.36	18.03
Coal	9.85	12.27	12.98	12.67	12.67	13.59	13.92	13.77	15.04	15.43	15.91	15.32	15.90	17.20
Nuclear Power	0.01	0.24	0.91	1.27	1.90	2.11	2.70	3.02	2.78	2.74	3.01	3.13	3.20	3.55
Hydroelectric Power[10]	1.66	2.65	3.01	3.31	3.22	3.07	2.51	3.14	3.14	3.12	3.11	3.56	3.87	3.78
Other[3]	([11])	0.02	0.05	0.06	0.07	0.08	0.08	0.07	0.09	0.11	0.13	0.11	0.13	0.17
Net Imports of Coal Coke	-0.01	-0.06	-0.01	0.06	0.01	([11])	0.01	0.12	0.06	-0.04	-0.02	-0.02	-0.02	-0.01
Total Consumption	43.81	66.44	74.29	72.55	70.55	74.37	76.29	78.09	78.90	75.96	73.99	70.84	70.50	73.73
Total Disposition	45.30	69.10	76.34	74.77	72.91	76.55	78.36	80.02	81.77	79.68	78.32	75.47	74.22	77.54

[1] Preliminary.
[2] Dry natural gas.
[3] Includes electricity produced from geothermal, wood, waste, wind, photovoltaic, and solar thermal sources connected to electric utility distribution systems (see Note).
[4] Includes imports of crude oil for the Strategic Petroleum Reserve, which began in 1977.
[5] Includes imports of unfinished oils and natural gas plant liquids.
[6] Includes coal, coal coke, and hydroelectric power.
[7] A balancing item. Includes stock changes, losses, gains, miscellaneous blending components, unaccounted for supply, and anthracite shipped overseas to U.S. Armed Forces.
[8] Includes natural gas, coal coke, and hydroelectric power.
[9] Petroleum products supplied includes natural gas plant liquids and crude oil burned as fuel.
[10] Includes industrial generation of hydroelectric power and net electricity imports.
[11] Less than 0.005 quadrillion Btu.

Note: Data do not include the consumption of wood energy (other than that consumed by the electric utility industry) which amounted to an estimated 2.6 quadrillion Btu in 1983 (see Table 86). This table also does not include small quantities of other energy forms for which consistent historical data are not available, such as geothermal, waste, wind, photovoltaic, or solar thermal energy sources except that consumed by electric utilities.

Note: Sum of components may not equal total due to independent rounding.

Sources: See sources for Tables 39, 60, 65, 70, 73, 75, and EIA estimates for industrial hydroelectric power, and conversion factors in the Units of Measure and Conversion Factors section.

Source: Annual Energy Review 1984. Energy Information Administration, U.S. Department of Energy (DOE/EIA-0384[84]), April 1985, p. 5.

Petroleum

In 1984, domestic crude oil production increased to 8.8 million barrels per day. For the first time since 1978, petroleum consumption increased, reaching 15.7 million barrels per day in 1984, representing 42% of the nation's total energy consumption. In fact, every end-use sector except electric utilities increased their oil consumption. The U.S. also increased its reliance on foreign oil sources for the second straight year, with OPEC countries currently supplying 13%. The world price of oil declined from a high of $35 per barrel in 1981 to near $29 per barrel in 1984.

Natural Gas

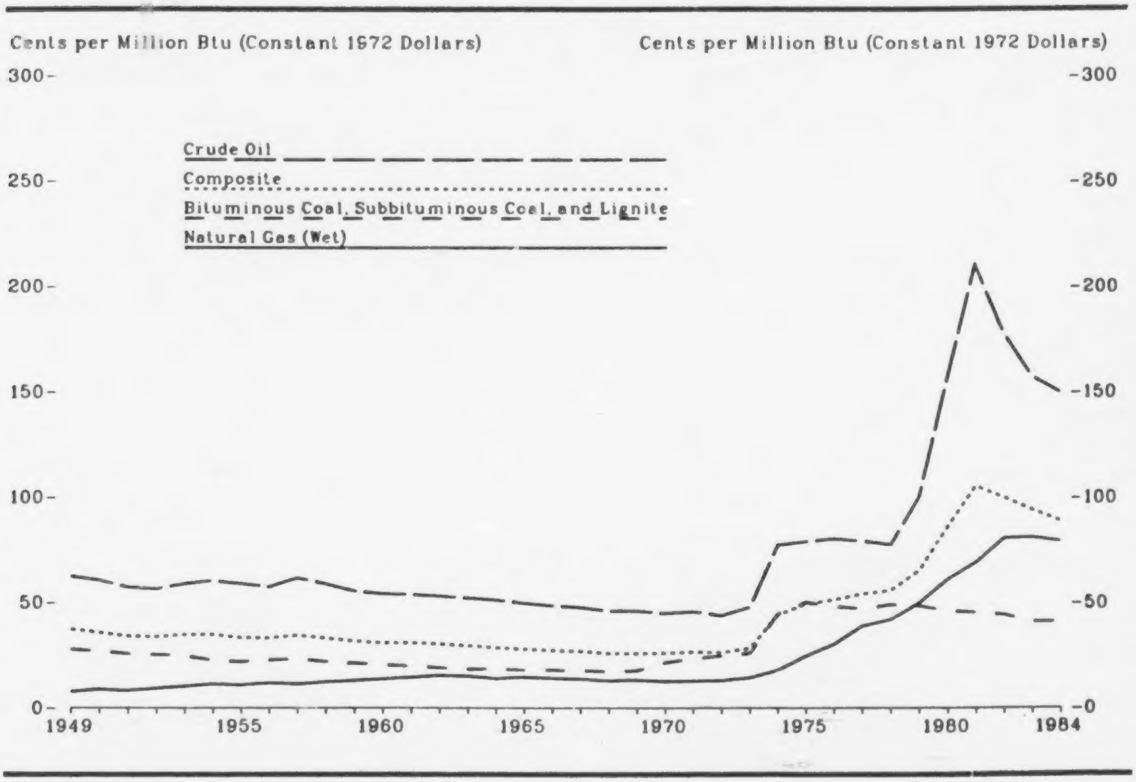
Natural gas consumption and production both increased in 1984, ending 4 years of decline. Consumption increased 4% relative to 1983, while production increased over 7% in the same period. Natural gas accounted for 24% of total energy consumption in the U.S. in 1984. The future of natural gas usage is uncertain in light of continued pricing decontrol, falling world oil prices, and current excess domestic gas suppliers' "bubble".

Coal

Coal production reached an all time high of 890 million short tons in 1984, exceeding the 1980 record of 838 million short tons. Production of coal west of the Mississippi continued to represent a growing share of total production, accounting for 34% in 1984. At the same time, domestic coal consumption increased nearly 8% as the effect of fuel switching continued in the industrial and utility sectors. Coal provided 23% of the nation's energy consumption. The future for domestic coal usage is clouded by efforts to repeal fuel use regulations prohibiting new oil and gas facilities in these sectors, and the uncertainty of "acid rain" legislation and its connection to new and existing coal burning plants.

FIGURE 1-3

FOSSIL FUEL PRICES, 1949-1984



Source: Annual Energy Review 1984. Energy Information Administration, U.S. Department of Energy (DOE/EIA-0384[84]), April 1985, p. 24.

Nuclear

The contribution of nuclear energy increased in 1984 by nearly 11% relative to 1983. By year end, 86 nuclear reactors were on line, six more than the previous year. Nuclear energy now accounts for 13.5% of electricity generation and is likely to continue to grow given that an additional 46 reactors remain in various stages of planning and construction. Government efforts to ease the licensing process in order to bring many of the unfinished plants on-line may be offset by the limited number of acceptable sites for radioactive waste and state utility commission disallowances of utility's full cost recovery for expenditures in new plant construction.

Renewable Energy

The traditional forms of renewable energy — wood and hydroelectric power — contribute nearly 8% or 6 quads of to U.S. total energy supply. Newer forms of renewable energy have been estimated to supply an additional quadrillion Btus. Some renewable energy technologies have moved into a commercial status; many others remain in a pre-commercial research, development and demonstration stage. While the contribution of many of the renewable energy systems is still slight in relation to the overall national energy supply, the relative progress is noted here.

- Biomass energy from a variety of resources (e.g. wood and wood waste, agricultural crops and residues, and municipal solid waste) now supply 3.0 - 3.5 quads of energy to the U.S.

- Geothermal energy reached nearly 1500 MWe of installed generating capacity in 1984, while direct applications provided 1,860 billion BTUs (0.002 quads) of thermal energy.

- Hydropower supplied 14% of the nation's electricity in 1984. While this is a reduction from 1983 (primarily due to a dry year), the growth of small-scale hydropower stations (many of which have come on-line since 1978) now number 1,410 with a combined capacity of 7,019 MWe.

- It is estimated that 200,000 homes and 15,000 nonresidential buildings employed passive solar design by the end of 1984. These designs can save up to 70% and 30% of the energy use of a residential and commercial building, respectively.

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- Photovoltaic cells, first conceived for space applications, are providing reliable power for a variety of applications, from tiny cells on hand-held calculators to utility power plants in the range of 1 - 5 MWe each. World wide shipments of photovoltaics cells amounted to 23.2 MWe compared to 3.4 MWe in 1980. The U.S. share slipped from 74% to 50% during the same time period.

- Solar water heating installations number over 800,000 in the U.S., supplying an estimated 17 trillion BTUs (0.017 quads) in 1984.

- High temperature solar thermal electric systems in the U.S. set world solar records in both size and output in 1984. These systems include a 10 MWe central receiver, 14.4 MWe parabolic trough system, and a 4.9 MWe (gross) parabolic dish system.

- An estimated 6,000 wind turbines totaling 700 MWe of generating capacity had been installed in the U.S. by the end of 1984. Electric output was 188 million kilowatt hours in 1984, providing enough electricity to meet the needs of nearly 38,000 average households. This represents significant growth since 1982 when less than 4.8 thousand kilowatt hours were produced.

Chapter 2

BIOMASS

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BIOMASS

RESOURCE AVAILABILITY

Unlike other renewable energy sources, biomass energy is derived from a variety of resources. The biomass resource base potentially includes hundreds of thousands of different plant species, various agricultural and industrial residues and processing wastes, municipal solid waste and sewage, and animal wastes. Current and potential uses of these resources vary greatly (see TABLE 2-1). Those biomass energy resources most likely to be commercialized in the U.S. will be discussed here. Conversion technologies utilizing these resources is contained in TECHNOLOGY DESCRIPTION.

TABLE 2-1

ESTIMATES OF ANNUAL U.S. BIOMASS ENERGY FEEDSTOCK PRODUCTION

(million dry tons/year)

Biomass Resource	Moisture Content	Total Available	Likely Utilization
Wood			
Mill residues	50%	149	130
Logging residues	50%	180	50
Thinnings from forest stand improvements	50%	47	47
Residential wood	50%	30	30
Mortality and excess over harvest	50%	310	30
Grains	15%	353	10-22
Crop residues	50%	473	80
Forage/Plant herbage	15%	750	130
Bagasse (sugarcane residue)	50%	4	4
Food processing wastes	70-90%	15	15
Aquatic plants*	70-95%	20	3-13
Industrial wastes	40-60%	100	23
Municipal solid wastes**	40-70%	136	66
Municipal sewage***	99%	13	10
Animal waste	85%	175	50
TOTAL		2755	678-700

* Does not include marine biomass.

** Personal communication, Donald Walter (U.S. DOE, Washington, D.C.)

*** Personal communication, Donald Klass (Institute of Gas Technology,

Source: Report On Biomass Energy. Energy Research Advisory Board to the U.S. Department of Energy, November 1981, pp. 83, 87.

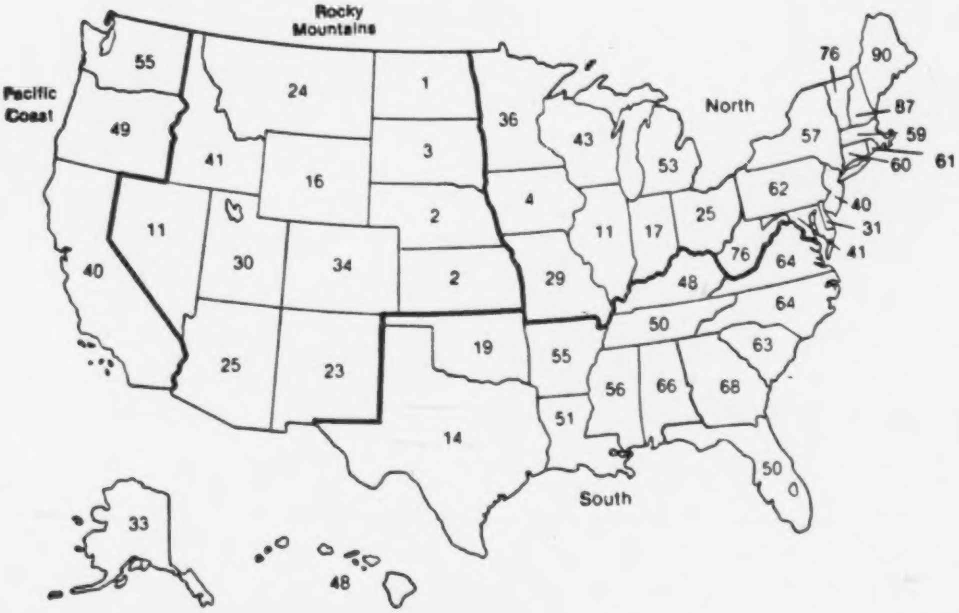
BIOMASS

Wood and Wood Waste

Wood remains the predominant biomass energy resource. One third of the continental U.S. (approximately 740 million acres) is forested, of which 66% is commercial forestland.(8) Commercial forestland is defined as being able to produce at least 0.3 dry tons/acre-year (0.1 dt/ha/yr) of timber in naturally stocked stands and is not designated parklands or wilderness, and is therefore considered the most likely source of timber for commercial energy use. The East (including the Northeast and Southeast) contains 74% of the total commercial forest acreage, most of which is privately owned (see FIGURE 2-1). All told, the estimated above ground standing timber (not including root biomass) in the U.S. commercial forestland is over 22 billion dry tons.(8) The present annual growth of trees in the U.S. forests is 800 million dry tons or 13.6 quads.(39)

FIGURE 2-1

FORESTLAND AS A PERCENTAGE OF TOTAL LAND AREA


Rocky Mountains
Pacific Coast
North
South
55
49
40
24
41
11
1
3
16
30
2
34
2
25
23
36
4
29
19
55
14
51
43
53
11
17
25
48
76
64
50
64
63
56
66
68
50
0
57
62
76
90
87
59
60
61
40
31
41
33
48

Source: Energy from Biological Processes (Vol. II - Technical and Environmental Analysis). U.S. Congress, Office of Technology Assessment, July 1980, p. 11.

Sources of wood biomass for energy, including mill residues, logging residues, thinnings from timber-stand improvements, harvests of residential fuel wood, dead trees, added growth in excess of harvest, and trees on short rotation plantations. The potential for wood waste utilization depends highly on collection and transportation costs.

- The development of *short rotation intensive crops (SRIC)* can increase traditional timber yields of 1.13 dry tons/acre-year (2.6 dt/ha/yr). SRIC relies on dense spacing of fast growing hardwood species, well prepared land, using fertilizer, herbicides and other agronomic techniques to maximize the production of energy wood. Energy plantations of eucalyptus and hybrid poplar have yielded harvest rates of 8.8 dry tons/acre-yr (20 dt/ha/yr).(39)
- The introduction of *densified biomass* (primarily wood waste) allows the fuel to be transported at lower cost than green wood chips, especially if transported 50 to 150 miles. Different forms of densification include pelletizing, cubing, briquetting, extrusion, and rolling-compressing. The process involves drying the wood, heating it until the lignin portion melts and then compressing it, the net result being a reduced moisture, higher heating value fuel that is easier to handle, transport and store. Pellets are the most common densified biomass form with 23 operating suppliers in Canada and the U.S.(42)

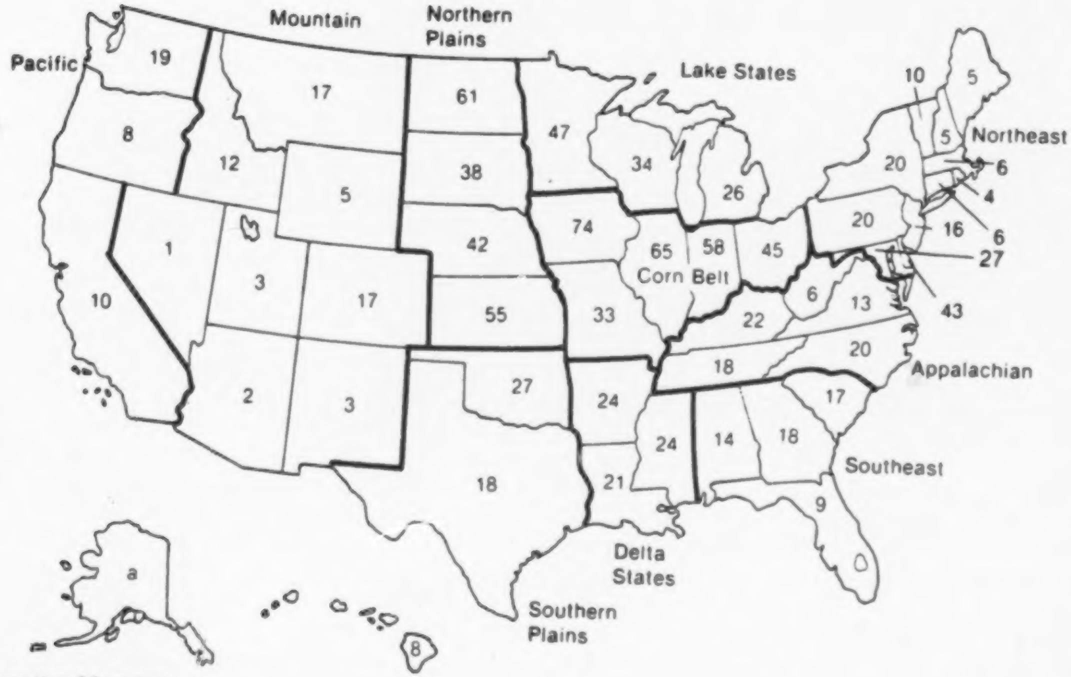
Agricultural Crops and Residues

Agricultural crops themselves offer an enormous potential biomass resource. Approximately 450 million acres are classified as cropland in the United States (see FIGURE 2-2).(8) Distribution of the resource is highly dependent upon water availability and soil quality. Because of primary use as a foodstuff and animal feed source, agricultural crop utilization for biomass energy is likely to be limited to surplus yields or output from marginal lands, and be relied on primarily for the production of high value fuels (e.g. corn for fuel ethanol). An estimated 30-70 million acres might be available for biomass energy production.(8)

FIGURE 2-2

CROPLAND AS A PERCENTAGE OF TOTAL LAND AREA

(By Farm Production Region)


Pacific
Mountain
Northern Plains
Lake States
Northeast
Corn Belt
Appalachian
Southeast
Delta States
Southern Plains
19
8
10
17
12
1
3
5
17
2
3
61
38
42
55
27
18
47
34
26
74
65
58
45
33
24
24
21
22
6
13
20
18
14
18
17
9
20
20
10
5
5
6
4
16
6
27
43
a
8

aLess than 0.5 percent

Source: Energy from Biological Processes (Vol. II - Technical and Environmental Analysis). U.S. Congress, Office of Technology Assessment, July 1980.

Although *agricultural residues and herbage* (lignocellulosics) constitute negligible energy supply at present, they have the potential for adding from 1.3 to 2.7 quads/year in the near-term.(8) Lignocellulosic forage crops (e.g., napier grass and sorghum) can be grown specifically for biomass yields. They are attractive because of high productivity (12 dry tons/acre-year [5.3 dt/ha/yr] or greater), low cost, and because some species can be grown on arid or marginal lands. Crop residues consist mainly of food processing residues, fruit orchard prunings, hulls and other residues left after the harvest and processing of agricultural biomass. Annual production rates for common crop residues include 1.2 - 2.2 tons/acre (0.5 - 1.0 tonnes/hectare) for vegetable crop residues; 1.0 - 4.5 tons/acre (0.4 - 2.0 tonnes/hectare) for field crop residues, and 0.4 - 2.5 tons/acre (0.2 - 1.0 tonnes/hectare) for orchard prunings.(2) About 20% of the material left behind after rice, grain and sugarcane harvests can be used as a viable energy source. The other 80% is needed to protect the soil from erosion or would be lost during harvest or storage.(7) For the near term, the utilization of crop residues for energy will occur on or near the source, primarily for agricultural processes.

Aquatic Plants

Aquatic plant biomass offers significant potential for energy use. These resources are not currently being used on an appreciable scale for food or industrial products and the composition of this biomass is not conducive for development of food or other critical applications. Both marine and fresh water plants are included in this resource base, with microalgae, macroalgae, floating and emergent plants being the types primarily considered for energy applications. They can be grown in fresh, saline and brackish water, as well as wastewater. Production rates for microalgae of 45 dry tons/acre-year (19.9 dt/ha/yr) have been obtained. Macroalgae, such as giant kelp is grown naturally in the open ocean and coastal areas, has high growth rates and produces significant amounts of carbohydrates. Water hyacinth, a floating plant, is one of the most productive plants in the world and can function effectively as a wastewater purifying agent as well as an energy source. A commercial facility in Florida has achieved sustained yields of 25 dry tons/acre-year (11 dt/ha/yr).(12)

Refuse Biomass

Refuse biomass is defined as organic waste material that has no current use and is otherwise discarded. The greatest energy potential from biomass refuse utilization is in the on-site or local use of wastes that are accumulated at central locations (e.g., municipal solid wastes, sewage sludge, and dairy and feedlot manures). Other residues such as wood, agricultural, and food processing wastes are described earlier.

Municipal solid waste (MSW) is being increasingly recognized as a valuable energy resource, especially as existing landfill sites are closed and the availability of new sites is limited. Total landfill in place and recoverable for energy purposes is approximately 1600-1700 million tons (1450-1550 million tonnes).(1) Converted to methane, this represents an energy potential of 108-115 billion SCF/year (3.06 - 3.25 billion m^3/year) of medium BTU gas(1). In addition, 108 million tons/year (98 million tonnes/year) of collected MSW are available for energy conversion.(1) Of this, the fuel fraction (primarily paper, wood debris, foodwastes, and to a lesser extent, plastics) represent about 69%, however, this fraction may be lower if some portion of the paper is recycled.(1)

Sewage sludge represents another captive resource. Current wastewater treatment by municipal utilities produces a high-moisture content effluent (sludge) which must be stabilized before it is landfilled. An estimated 6 million tons (4.5 million tonnes) of sludge are produced each year.(9) The high organic content and slurry nature of this resource makes it ideal for anaerobic digestion, a stabilization process and energy conversion technology, with an estimated potential of 40 billion SCF/year (1.1 billion m^3/year).(1)

Dairy and feedlot manure has been recognized throughout the world as an energy source. Estimates of the animal wastes generated in the U.S. are about 190 million dry tons/year (194 million dry tonnes/year), 55 million tons (50 million tonnes) of which is currently being used as fertilizer.(12) Large feedlots account for less than 15% of this resource and since it is relatively expensive to transport manure long distances, the majority of the resource used for energy will come from small, on-farm applications.(8)

TECHNOLOGY DESCRIPTION

Biomass energy comes from converting a feedstock into a useful form of energy. Although virtually all biomass feedstocks are originally derived from the photosynthetic conversion of sunlight, water and carbon dioxide into carbohydrates and oxygen by plants and algae, the term has been expanded to include secondary resources such as animal wastes and the organic portion of municipal solid wastes (MSW). The feedstocks are converted via a multitude of technologies into gaseous, liquid or solid fuels and applied to a variety of end-uses. The energy content (BTU/lb) of the biomass feedstock and conversion efficiency of the specific technology determine the net energy output of any system. TABLE 2-2 indicates the energy content of several biomass and non-biomass feedstocks.

TABLE 2-2

ENERGY CONTENT OF CERTAIN SOLID FUELS

Solid Fuel	Higher Heating Value BTU/lb (dry weight)
Coal	10,500-14,000
Charcoal	13,370
Wood/wood waste*	4,000-9,500
Crop residues	6,000-6,500
MSW*	7,500-8,500
Animal Manure	7,380

* Personal communication, Donald Walter (U.S. DOE, Washington, D.C.)

Source: Energy from Biological Processes. Volume II, Office of Technology Assessment, U.S. Congress, July 1980, p. 124.

The conversion technologies can be divided into thermochemical (those requiring heat) and biochemical (those requiring microorganisms) conversions. Among the thermochemical conversions are direct combustion, gasification, pyrolysis, and liquefaction. The biochemical conversions include anaerobic digestion and fermentation.

Thermochemical Conversion

Direct combustion is probably the most common conversion process whereby solid biomass (e.g., wood, wood waste, crop residues, municipal solid waste) is burned in a confined container, stove or boiler. Combustion is maintained by air flow through the combustion chamber. Optimal air flow and properly dried biomass greatly enhance the efficiency of the combustion process. The size of direct combustion systems vary significantly from household woodstoves and furnaces to utility-scale, multi-megawatt wood and municipal solid waste facilities. Emissions from all sizes of combustion systems are a concern; therefore, proper pollution control devices and feedstock selection are important.

Gasification is a process of turning solid biomass into a combustible gas. The solid biomass is partially burned in the presence of air or oxygen to produce a low- or medium-BTU gas.

Pyrolysis is the process originally used to produce charcoal. Here solid biomass is heated in the absence of oxygen or air to form char (charcoal) that comprises about 30% by weight of the feedstock and contains 42% of its BTU content. It also yields a pyrolytic oil that carries about 32% of the feedstocks BTU content, as well as a high BTU gas. This resulting gas can be used to produce liquid fuels such as methanol.(12)

Liquefaction mixes solid biomass with carbon monoxide and a catalyst to produce a heavy, low grade oil. The oil is high in oxygen content and low in hydrogen content, and requires substantial hydrogenative upgrading to be used as a premium fuel.(12) The low grade oils that are produced can be used as boiler fuel without further processing.

Biochemical Conversion

Anaerobic digestion uses bacteria to break down organic wastes (e.g., animal manure, aquatic plants, sewage sludge, MSW) in an oxygen free environment to produce biogas (methane and carbon dioxide gas). The container system used (digestor) varies greatly including single or multiple tanks, single or multiphase, batch, packed bed, expanded bed, mixed bed, and variable bed systems. Efficiencies of these systems is determined by the feedstock used, temperature required, and most importantly the quality of the biogas produced (less carbon dioxide the better). In fact, methane can be naturally produced from a closed landfill (landfill gas) via anaerobic digestion. In this case a cap of dirt covers the landfill and the methane gas is tapped through a series of wells. The effluent from the anaerobic digestion process also provides a valuable fertilizer and contains less of its original odors.

Fermentation is the major process used to produce ethanol fuel. Biomass (such as corn, sugarcane, and wood) are broken down to basic sugars which are then converted to ethanol by yeast or other microorganisms. Sugar feedstocks yield fermentable sugar usually concentrated into a syrup. Starch feedstocks need treatment with enzymes or acid to breakdown the starch into sugar. Cellulosic feedstocks such as wood require more extensive hydrolysis treatment in order to reduce the cellulose to sugar. Once the sugar is fermented to form ethanol, the solution is distilled to reduce or remove water content. Solutions of 198 proof (99%) ethanol is considered anhydrous (without water).

APPLICATIONS

Electricity is produced from the combustion of solid or liquid biomass fuels in a boiler connected to conventional steam turbines. Conventional gas turbines can run gaseous biomass fuels. Biomass fuels can be used in a dedicated boiler or co-combusted with fossil fuels such as oil, coal and natural gas. Methane from anaerobic digestion is being applied to a fuel cell to produce electricity directly without combustion. Biomass electric generators can range from several kilowatts to 50 MWe or greater.

Thermal energy for agricultural and industrial processes is derived from the combustion of solid biomass such as wood and agricultural wastes primarily as a substitute for more expensive sources of energy as well as a means of eliminating waste by-products. Lower temperature applications (such as crop drying) can come from the thermal energy generated in the anaerobic digestion process. The combined use of biomass for the purpose of producing electricity and useful thermal energy (*cogeneration*) is gaining interest due to increased overall efficiencies of the process, and regulatory support.

Solid biomass fuels (primarily wood) are being used widely for residential space heating through the use of fireplaces, wood stoves and small furnaces. It should be noted that in the U.S. much of today's wood combustion in open fireplaces is more for aesthetic reasons than for its thermal output. Wood and biogas fueled cook stoves are used widely in many developing countries and to a lesser extent in the U.S.

Transportation fuels is another important application of biomass. Liquid fuels such as ethanol and methanol can be used as a gasoline additive (fuel extender) or can serve as a replacement fuel in a modified internal combustion engines. Both ethanol and methanol are considered octane enhancers, in that a 10% ethanol or methanol to gasoline blend will raise octane 3-4 points.

TECHNOLOGY STATUS

The current status of biomass conversion technologies is as varied as the resources themselves. Some processes such as gasification and direct combustion have been used historically and have seen renewed interest following the energy crises of the 1970s. Others such as fermentation and pyrolysis were not originally developed for energy purposes, but have been modified to produce liquid fuels in order to replace premium fossil fuels.

Residential Wood Combustion Systems

Fireplaces, the most common direct combustion systems, have been historically used in residences for space heating, yet, today's standard designs serve more often for recreational or aesthetic value. On the other hand, a modern, well-designed and operated Rumford fireplace with a fully closeable damper can deliver about 15% thermal efficiency.(43)

Attempts at increasing fireplace efficiency without altering its basic character include prefabricated open fireplaces, glass door kits and various retrofit blower kits. "High tech" fireplace inserts, high efficiency modular fireplace units, and integrated "energy system" fireplaces, offer the appeal of open fireplaces while providing 35% or greater overall efficiencies.(43) The cost of fireplace modification systems range from $100-$300 for simple glass door kits to $4,000-$6,000 for integrated system fireplaces used for central heating.(43)

Woodstoves constructed of cast iron, soap stone, or ceramic material are perhaps the most common biomass residential heating units. A free standing woodstove is typically 50-65% efficient.(44) The introduction of airtight, regulated air flow, secondary combustion mechanisms, multiple heat exchangers, and most recently catalytic combustors have revolutionized woodstove technology. Most woodstoves employ thermal mass of firebrick or other material to help moderate heat transfer to the living area, as well as extending the burning time of a single load of wood. High technology woodstoves utilizing stoker driven, pelletized fuel and other modifications offer efficiencies in excess of 90%. Prices for residential woodstoves range from $300 for cast iron models to $1,500 for units adorned with brass, glass and other features. Both catalytic and non-catalytic stoves are available that reduce, up to 90%, the emission of harmful air pollutants, including particulate matter and certain carcinogens.(22) Catalytic equipment, on the average, add $125-$200 to the retail cost of stoves.

There are three basic types of *wood furnace* installations: the wood-only furnace, the multi-fuel furnace, and tandem systems retrofitted to existing conventional furnaces. Substantial work has been done since the early 1970s to make systems both more efficient and automatic. Thermostat control devices (some employing a microprocessor), automatic fuel feeding mechanisms, and extended heat storage capacity are among the technology advancements that will help wood furnaces replace central furnaces in residential applications. Today, advanced systems are available for $1,000 to $3,000 and offer thermal efficiencies in excess of 70%. In general, woodstoves and furnaces require more labor than oil or gas heat. The fuel requires more handling, ashes must be removed and regular cleaning of stovepipes is suggested.

Large-Scale Biomass Combustion Systems

Direct combustion systems utilizing wood, wood waste, and crop residues for industrial and agricultural process heat/steam, as well as for electricity production or cogeneration are available. Cogeneration is an efficient direct combustion application with conversion efficiencies of about 70% compared with 30% for electricity production from dry biomass.(12) The choice for cogeneration depends on whether the heat/steam energy can be used to meet thermal energy requirements, while electricity can be used on-site or sold to a nearby utility.

Current cost and performance improvements are focused on fuel preparation, handling, transportation and storage processes, as well as improvement in the conversion technology itself. Chipped or densified biomass add considerably to a project's initial capital cost, however, improvements in conversion efficiency (through the use of more specialized boilers) and reductions in transportation and storage expenses may offset the additional costs. In addition, refined wood fuel can effectively be co-combusted with fossil fuels in traditional boilers with minor modifications.

Biomass boilers are differentiated by their means of combustion and system configuration. These include *pile*, *cyclone/suspension*, and *fluidized bed* systems. For the most part, commercial biomass reactors used for direct combustion and gasification are modifications of coal technologies.

- *Pile burners* are the most simple and straight forward combustor. Solid biomass is piled on a wet grate where air entering from the side and bottom provide initial gasification and combustion. In a second chamber, additional air is added to complete combustion and water is heated in tubes to make steam. Different grate configurations and feed mechanisms have modified the pile burner to increase thermal and combustion efficiencies. These include inclined, moving, traveling, dump and rotary grates. Overfeed, underfeed and spreader stokers have been employed to distribute the fuel and regulate feeding rates. In general, pile burners can utilize wood particles of various sizes and high moisture content, yet they operate at lower efficiencies than other combustors.(8)

- *Cylone and suspension burners* have enabled higher efficiencies and easier scale up in capacity. Here the fuel is forced into the combustion chamber by a stream of pressurized air and is kept in suspension while it is burned. Cyclone and suspension burners require dry (15% moisture content) and properly sized (less than 1/4 inch) wood. Higher thermal efficiencies and faster feeding rates are obtained, yet concern exists over particulate emissions.(8)

- *Fluidized bed burners* utilize the mixing action of a hot bed material (e.g., sand) to help ensure that the fuel is completely burned. Fluidized bed systems provide high thermal efficiencies by rapidly heating the fuel while providing plenty of combustion air. These burners generally have higher initial costs but can handle biomass with high moisture content and irregular size.(8)

Waste-to-Energy Systems

Direct combustion of municipal solid waste (MSW) began at approximately the same time in the U.S. and in Europe. However, because of cheap fuels and available land, the U.S. tended toward landfilling and using incineration primarily to reduce volume, while European systems focused on energy production. The first major refuse-to-energy plant in the U.S. of sizable capacity was established in 1967 compared to 1950 in Europe. In fact, every plant over 720 tons/day (650 tonnes/day) capacity in the U.S. has been built using European technology through U.S. licensed firms.(5) Today, all operating refuse-to-energy plants are of two categories; those which burn non-segregated MSW in specifically designed furnaces to recover steam or hot water (mass-burn) and those which remove recoverable materials such as glass and metal, concentrating the organic fraction into refuse derived fuel (RDF).

The *mass-burn* MSW facilities can be divided into two distinct groups: field erected and modular units. The field erected units are custom designed to meet the requirement of the particular site, often exceeding 1000 tons/day (900 tonnes/day) capacity. The modular factory assembled units are a unique U.S. development originally intended for incinerators but later adapted to recover steam and provide automatic ash handling for 24 hours/day operation. Although originally designed for less than 50 tons/day (45 tonnes/day) modular MSW plants have begun to incorporate multiple modules, increasing the average capacity of installations to over 90 tons/day (82 tonnes/day) by 1985.(4)

As modular MSW facilities have grown in size, the distinction between these and field erected units has become less distinct. Modular systems now employ vibrating grates and pit and crane waste handling systems, while field erected systems utilize prefabricated boilers (sometimes in two pieces) requiring minimal assembly. The primary difference remains in the size of the facility. The combined capacity of all modular facilities currently operational or under construction is just 3200 tons/day (2909 tonnes/day), not much more than the capacity of one of the large water-wall mass burning systems constructed recently.(4)

In general, *refuse derived fuel (RDF)* facilities are designed using components developed for other applications. Combustion chambers and steam raising components often use engineering "rules-of-thumb" and consequently do not optimize overall performance.(5) The separated organic portion of RDF may be recovered as fluff (essentially shredded paper), densified (fluff compressed into pellets or briquettes), and powder. The fluff and densified RDF may replace up to 20% of the energy (BTU/lb) of coal in existing boilers or may be burned in specialized boilers. Powdered RDF has the capability of displacing up to 20% of the fuel oil in existing boilers.(5) TABLE 2-3 indicates the status of the various waste-to-energy technologies.

Since most *industrial applications* require steam, some heat transfer mechanism must be employed. Two types of heat transfer designs -- firetube and watertube -- comprise the majority of applications. In firetube boilers the heat travels through the tubes about which water circulates. The converse is true for watertube, in that, the water is circulated through tubes. Firetube boilers have advantages in smaller applications. They have lower capital costs and require less maintenance and water treatment. The watertube boilers are easier to scale-up and offer greater safety. For most industrial process systems, the capacity of the biomass system is limited by the load or demand for heat or steam by the end-use facility.

TABLE 2-3

STATUS OF BIOMASS WASTE-TO-ENERGY FACILITIES IN THE U.S.

	Operating Before 1980	Operating 1980 & On	Under Construction	Advanced Planning	Planning	Shut Down	Total
Design Capacity (TPD)							
0-49	3	2	2	0	0	1	8
50-500	11	33	10	28	87	11	180
501-1,000	3	1	3	7	30	4	48
1,001 +	5	10	4	8	30	4	61
Total	22	46	19	43	147	20	
Technology							
RDF/DED[1]	1	4	1	2	3	0	11
RDF/COF[2]	5	7	2	7	6	12	39
Refractory	6	5	4	3	11	2	31
Waterwall	7	7	3	15	24	1	57
Modular	3	20	5	16	34	4	82
Compost	0	0	0	0	4	0	4
Mass Burn/NS	0	3	4	0	8	0	15

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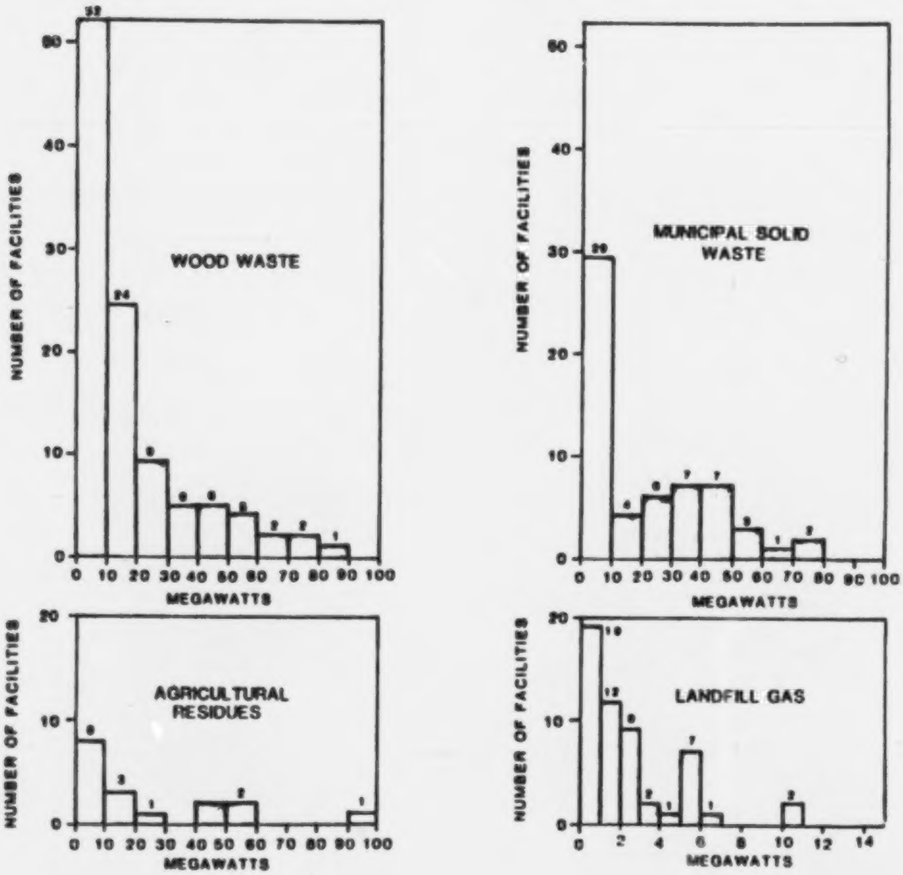
1. Refuse Derived Fuel/Co-Fire.
2. Refuse Derived Fuel/Dedicated Boiler.

Source: Harvey W. Gershman, "Solid Waste-to-Energy Overview and Status Report," 12th Energy Technology Conference and Exposition (Government Institutes, Inc., Washington, D.C., March 25-27, 1985, p. 3.

The steam turbine is the standard tool for *electric generation* from biomass. However, turbine design mandates progressively lower efficiencies for facilities of 100 MWe or less. Those used for solid biomass now have to settle for heat rates of 12,000-15,000 BTU/kW for systems of 5-50 MWe in capacity.(9) The optimum size of a biomass fueled electric plant is determined by a trade off between the economy of scale and the cost of transporting the feedstock to the combustion facility. Under most circumstances, the local availability of feedstock limits the size of biomass conversion facilities to the equivalent of 60 MWe electric or less.(8) The current size range and frequency of various biomass electric generating facilities is listed in FIGURE 2-3.

FIGURE 2-3
NUMBER AND CAPACITY OF BIOMASS-FUELED FACILITIES



Source: James L. Easterly (Meridian Corporation) and Elizabeth H. Saris (Science Applications). Electrical Power from Biofuels (revised). U.S. Department of Energy (DE-AC01-83CE-30784), January 1985, p. 30.

Landfill Methane Gas

Landfill gas is another important waste-to-energy technology. Here a closed landfill is covered with an impermeable surface of dirt or clay. Once significant volumes of raw gas have accumulated, shallow recovery wells (30-100 feet deep) are drilled into the landfill.(33) A pressure differential is established between the landfill and the collecting wells through the use of an industrial compressor. However, care must be taken in order to avoid drawing air into the landfill and destroying the oxygen free environment.

Projects range from 0.4 - 5 million ft^3/day (12,000-150,000 m^3/day) producing either high-BTU gas (850-1000 BTU/ft^3) or medium-BTU gas (500-850 BTU/ft^3).(33) The raw methane gas produced by closed landfills has approximately the same energy content initially (45-550 BTU/ft^3), but is often upgraded through membrane separation to achieve a higher heating value necessary for certain end-uses. Closed landfills currently range from 21 acres to over 500 acres (8.4 - 200 hectares) in size and range from 50 to 300 feet (15-90 meters) in depth.(33)

The methane produced by closed landfills is being increasingly used for *electricity generation* in gas turbines or reciprocating engine generators. Current systems are all 10 MWe or smaller, with the majority being less than 1 MWe installed capacity (see FIGURE 2-3).(25) A pilot plant has been built that uses the gas from a nearby landfill to operate a 40 kw fuel cell.

Gasification

Solid fuel gasifiers were first developed in England during the late 1700's to produce gas intended to drive internal combustion engines. Stationary wood gasifiers emerged in England in the 1800's and by the early 1900's, and the technology had advanced to the point where virtually any type of cellulose feedstock could be gasified.(28) However since that time, most gasification research has focused on coal utilization. The height of interest in gasification came during World War II when competition for limited petroleum supplies lead many European nations to apply the technology to their transportation fleets. By 1944, more than 80% of Europe's trucks and other large vehicles and 26% of civilian vehicles were running on producer gas derived from wood, coal, charcoal, peat, and coke.(27) After the war, the return of inexpensive gasoline and diesel fuel diminished interest in biomass gasification.

Currently in the U.S., biomass gasification hardware for the production of low- and medium-BTU gas is commercially available from many vendors, but relatively few plants have been constructed and commercially operated over extended periods of time. Many designs of biomass gasifiers exist, with most of the emphasis focused on fairly small units on the order of 100 million BTU per hour (mmBTU/hr) or less.

Four general types of biomass gasifiers exist: fixed-bed updraft, fixed-bed downdraft, moving bed and fluidized bed.

- The *fixed-bed updraft gasifier* is the oldest type. Process air is introduced into the chamber at the grate or bed and a combustion zone is established at approximately 2500°F. Combustion gases travel up through the bed, exiting at the top. The exiting gas is relatively cool, about 200°F. The advantages to this design is its simplicity and ability to utilize a wide variety of fuel forms, sizes and moisture contents. Disadvantages, due to the low temperature of the exiting gas, are that the gas cannot be transported because tar and other liquids condense easily. Consequently, updraft gasifiers should be close-coupled to their end-use. In addition, the current size or output has been limited to 100 mmBTU/hr.(28)

- The *fixed-bed downdraft gasifier* is similar to the updraft design except that the process air is introduced at or above the combustion zone and the product gas is drawn through the combustion zone, exiting near the bottom of the chamber. As a result, the exiting gas contains less tar than in updraft systems. Downdraft systems are limited to less than 30% moisture content wood, and only rarely have they been scaled up for use of anything larger than modified car or truck engines (5 mmBTU/hr).(28)

- The *moving grate gasifier* is similar to designs commonly using coal. Here combustion and gasification are regulated by process air flow and the producer gas is drawn into an adjacent boiler. Due to the experience learned through the use of coal, moving grate systems appear likely to be able to be scaled up to large sizes. However, there are limitations in the types of acceptable feedstocks. Neither finely divided fuels (such as sawdust), nor stringy fuels like bark are compatible with the grate.

- *Fluidized bed gasifiers* have been developed recently which promise greater capacity and gas production rates than fixed bed types. Because of the high temperature of the exit gas, it can be transported longer distances than gas produced by other types of gasifiers. In addition, fluidized bed gasifiers have the advantage of flexibility in feedstock utilization (size and moisture content) because they lack a grate or static bed. Fluidized bed gasifiers can also be scaled up to sizes on the order of 200 mmBTU/hour without significant engineering modifications.(28) Disadvantages of the system include increased particulate emissions, as well as the need for auxiliary heat source to preheat the bed. Overall process efficiencies are high for fluidized bed systems with about 80% of the wood (by weight) being converted to gas.

Pyrolysis

Pyrolysis gasification in an oxygen or air starved environment, has been used for centuries to make charcoal and wood distillates. Optimization of the pyrolysis reaction including short residence time, reduced pressure, lower combustion temperatures, heat-up and quenching rates can greatly increase the liquid yields. The reduced pressure during thermal decomposition of biomass increases yields of organic liquids pyrolytic oil to 45-65% by weight. This compares favorably to conventional pyrolysis yields of 20-25%. Recently, new technologies have been developed to use fluid bed and flash pyrolysis in an effort to increase gas and liquid yields. Using rapid heating rates, yields of pyrolytic oils and gases as high as 95% can be reached.(26) While the oils differ chemically from petroleum liquids, the low projected cost of the pyrolytic oils indicate that upgrading to fuel oil quality may be economically feasible. The pyrolytic gases can undergo treatment to produce high value aromatic hydrocarbons such as benzene, toluene, zylene, and ethylene, or liquid fuels such as methanol.(26)

Liquefaction

Liquefaction converts biomass by reacting it with a reducing gas in the presence of a catalyst.(39) The product is a refinable heavy oil which can refined for use as a boiler fuel or chemical feedstock. Most liquefaction processes are hampered by difficulties in pumping highly concentrated wood slurries, requiring oversized reactors to achieve desired output. Current work on biomass liquefaction is concentrated on catalyst improvement, thermodynamic and kinetic modeling, pumping system development and overall process optimization. Of all the thermochemical conversion processes, liquefaction remains the furthest from commercial status. However, the desire to develop a liquid fuel substitute to petroleum will ensure continued technological research and development.

Anaerobic Digestion

The use of methane derived from the decomposition or anaerobic digestion of organic wastes for energy dates back to 1895 when the gas from a carefully designed septic tank was used for street lighting in Exeter, England.(31) By the 1920's, several systems were specifically designed and built for the production of methane gas. Since that time, the majority of technological development and process optimization has occurred in small waste digestors for rural applications. Use of the technology has expanded, however, so that today, the anaerobic digestion systems are found on small farms, food processing industries, and waste processing facilities. In all cases the process occurs when various kinds of bacteria consume plant or animal material in the absence of air to produce a volatile gas known as biogas. Specifically designed air-tight containers that promote anaerobic digestion are called digestors. Even closed landfills with a dirt or clay cover operate as anaerobic digestors.

Temperatures between 68-140°F (20-60°C) favor bacteria that release biogas (50-70% methane) -- essentially natural gas -- with the remainder being primarily CO_2 with traces of nitrogen, hydrogen, and hydrogen sulfide. The biogas has a heating value equal to its methane component, 500-700 BTU/ft^3.(8) The gas can be purified by removing the CO_2 portion making it suitable for pipeline distribution. On the average, about 15% of the energy produced is used to heat the feedstock entering the digestor.

BIOMASS

The best feedstocks for anaerobic digestion are wet biomass such as fresh animal manure, various aquatic plants (e.g., algae and water hyacinth), and wet food processing wastes such as those found in the cheese, potato, tomato, and fruit processing industries. Since dewatering of the feedstock is not necessary, anaerobic digestion does not compete with other biomass conversion processes for potential feedstocks. In addition, the anaerobic digestion process is especially well adapted to slurry-type wastes (such as sewage sludge) and has environmental benefits in the treatment of wastes, reducing odor nuisances, and producing an organic fertilizer. The anaerobic digestion process has had a long history in the stabilization of municipal sewage. There is also research being conducted on conversion of agricultural residues, MSW, and wood wastes since methane is a desirable biomass fuel. TABLE 2-4 provides estimates of biogas yields for a variety of biomass feedstocks.

TABLE 2-4

ESTIMATES OF BIOGAS YIELDS FOR VARIOUS FEEDSTOCKS

Feedstock	Biogas Yield ft^3/lb (dry weight)
Cattle manure	3.1 - 8.0
Beef manure	13.7 - 17.7
Chicken manure	5.0
Poultry manure	7.3 - 8.9
Swine manure	7.9 - 16.3
Sheep manure	5.9 - 9.7
Algae	5.1
Water hyacinth*	6.7
Sewage sludge*	4.7 - 7.3

* Donald Klass, "Energy from Biomass and Waste: 1984 Update," Institute of Gas Technology, 1985.

Source: Methane Generation from Human, Animal, and Agricultural Wastes. National Academy of Sciences, 1977, p. 66.

The capacity of anaerobic digestors vary from less than 1,500 to 4 million gallons and are of a variety of configurations. Scale up for digestor systems is less of a problem than for thermochemical conversion systems because the digestors are usually of a fixed size, and more modules can be added to achieve the desired capacity or production rate.(5)

The major digestor categories include batch and continuous flow (see FIGURE 2-4). Batch systems are the simplest and least expensive designs and can be operated intermittently with small loads. In a *batch system*, the raw material is placed in an air-tight, oxygen-free tank or pond and left to ferment. Once the digestion is complete, the system is recharged without removing the effluent. In a *continuous flow system*, the raw material can be fed and gas removed during the process without disrupting the digestion process. There are three types of continuous digestors: horizontal, vertical and multiple phase.

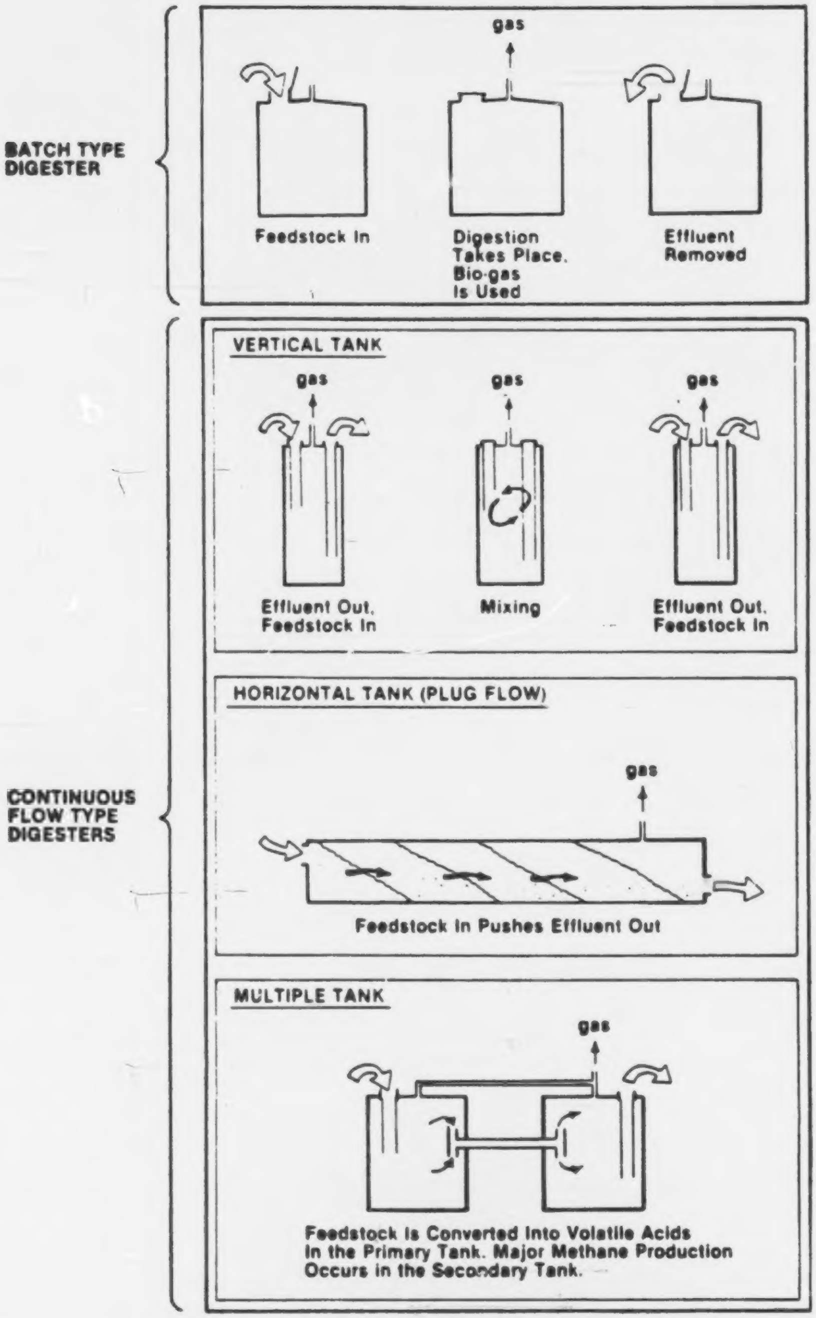
- *Vertical tank systems* use an upright, oxygen free container which is loaded and unloaded from the top. The system is operated by removing some of the processed waste and replacing it with an equal amount of fresh feedstock. The resulting new feedstock is then mixed either mechanically or by pumping biogas back through the system.

- *Horizontal tank systems* (also known as plug flow digestors) are fed from one end with an equal amount of processed waste being removed from the other end. This system is particularly effective in processing waste that is about 10% solid.(32)

- *Multiple phase digestors* are used to enhance biogas yield by separating the anaerobic digestion process into two phases and optimizing the condition for both. In the first phase, an acid-forming bacteria converts the complex fats, carbohydrates, and proteins into simple compounds called volatile acids. The second phase involves a methane-forming bacteria which converts the volatile acids into biogas. Although both phases are present in all anaerobic digestors, the two phase system operates by tailoring the temperature and pH of each tank to the ideal conditions for each type of bacteria, hereby allowing an increase in methane content of conventional digestors (normally 55-65%) to 75-95%.(6)

FIGURE 2-4

BATCH TYPE AND CONTINUOUS FLOW TYPE DIGESTORS


BATCH TYPE DIGESTER
gas
Feedstock In
Digestion Takes Place. Bio-gas Is Used
Effluent Removed
CONTINUOUS FLOW TYPE DIGESTERS
VERTICAL TANK
gas
gas
gas
Effluent Out. Feedstock In
Mixing
Effluent Out. Feedstock In
HORIZONTAL TANK (PLUG FLOW)
gas
Feedstock In Pushes Effluent Out
MULTIPLE TANK
gas
Feedstock Is Converted Into Volatile Acids In the Primary Tank. Major Methane Production Occurs in the Secondary Tank.

Source: An Introduction to Biogas Production on the Farm. National Center for Appropriate Technology, U.S. Department of Energy (DE-AC01-82CE15095), March 1984, p. 6.

Fermentation Ethanol

Ethanol or grain alcohol is a versatile and commercially important liquid which has been used for centuries for a variety of purposes. Over time, the technique of distillation was developed to increase ethanol concentration, and ultimately a pure or anhydrous (without water) state was produced. Today, ethanol fermentation is feasible using a variety of biomass feedstocks including grains, sugar crops, woody material and even municipal solid waste. Ethanol can also be produced by synthetic methods, the primary route being catalytic hydrolysis of ethylene from petroleum.

Ethanol has been used considerably as a solvent or reactant in the manufacture of chemicals, plastics, and fibers. Its use as a combustion fuel for transportation and space heating diminished in the second half of this century, being displaced by petroleum-based motor and boiler fuels. Oil price increases during the 1970s renewed interest in ethanol as a transportation fuel and public and private sector research and development was initiated. Current fuel ethanol technology development efforts are targeted at reducing process energy requirements, increasing feedstock diversity, enhancing conversion process efficiencies, and decreasing production cost.

Ethanol distilleries use substantial amounts of fuel in converting the feedstock to fuel grade ethanol. An efficient 50 million gallon per year distillery will consume slightly more fuel than a 30 MWe power plant. Research in response to concern about the the energy balance (energy input: energy output) of U.S. ethanol production technology revealed that roughly 1.5 times more energy is produced than consumed, including energy inputs required for planting and harvesting the feedstock. Brazilian processes, using sugarcane as a feedstock and the residue (bagasse) as a primary fuel source, have revealed a 9 to 1 energy ratio. In 1984, energy inputs for U.S. ethanol processes were primarily derived from fossil fuels (natural gas: 63.4%, coal: 30.3%, and wood and other sources: only 4.3%).

Feedstock diversity provides another challenge for ethanol technology in the U.S. and elsewhere. Corn and other grains remain the primary U.S. feedstocks, accounting for approximately 75% of all feedstocks used. Other starch crops, such as barley, are beginning to be utilized. Sugar crops are widely used in Brazil but are less available in the U.S. At this time, crop availability (surpluses) direct feedstock choice. TABLE 2-5 provides ethanol yield estimates for a variety of feedstocks.

Alternative (non-grain) feedstocks and conversion processes to use them are being developed. The conversion of cellulose material such as wood, grasses, and crop residues through acid hydrolysis offers great potential. While commercial wood to ethanol plants are in operation only in the U.S.S.R. and Japan, several other countries, including Canada, expect to utilize the century-old technology. Advanced enzymatic hydrolysis processes are being developed in the U.S.

TABLE 2-5

YIELDS OF RAW MATERIALS USED IN ETHANOL PRODUCTION

Raw Material	Yield (tons/ha/yr)	Ethanol (liters/ton)	Ethanol (liters/ha/yr)
Sugarcane	50-90	70-90	3,500-8,000
Sweet sorghum	45-80	60-80	1,750-5,300
Sugar beet	15-50	90	1,350-5,500
Fodder beet	100-200	90	4,400-9,350
Wheat	1.5-2.1	340	510-714
Barley	1.2-2.5	250	300-625
Rice	2.5-5.0	430	1,075-2,150
Maize	1.7-5.4	360	600-1,944
Sorghum	1.0-3.7	350	350-1,295
Irish potatoes	10-25	110	1,110-2,750
Cassava	10-65	170	1,700-11,050
Sweet potatoes	8-50	167	1,336-8,350
Grapes	10-25	130	1,300-3,250

Note: These figures are derived from many sources and are included only as indications of possible yields, depending on widely varied conditions.

Source: Alcohol Fuels: Options for Developing Countries. National Academy of Sciences. Washington, D.C.: National Academy Press, 1983, p. 7.

The cost of producing ethanol is another area of potential improvement. Current ethanol production costs from grain feedstocks vary from \$1.20-1.40/gallon, but generally exceed the retail cost of gasoline. The major operating expense is the feedstock cost (less the by-product) and the fuel or energy costs. Processes in Brazil using sugarcane as a feedstock and bagasse as a fuel source have achieved a production cost of about \$0.80/gallon. The cost of ethanol in the U.S. could be reduced \$0.20/gallon by avoiding the need to achieve an anhydrous state.(5) Typically, it is easier to produce ethanol containing 5% or more water. Further, the development and use of micro-emulsifiers would enable the blending of 180-190 proof or lower ethanol content in gasoline (micro-emulsifiers prevent water from separating out of the ethanol/gas blend).

GOVERNMENT SUPPORT

Federally supported research and development for biomass energy has been in place for 11 years, through a variety of government agencies. The current U.S. Department of Energy support is contained in the Biofuels and Energy from Municipal Waste Programs. The objectives of DOE's biomass energy R&D efforts are to provide the technological base for feedstock production and conversion of organic materials which will enable the biofuels industry to significantly contribute to long-term U.S. energy needs. The budget for the Biofuels Program has been fairly constant over recent years as the diversity of biomass resource and conversion technologies offer significant improvements over current usage (see TABLE 2-6 and FIGURE 2-5).

In addition to the Department of Energy, twelve other federal departments and agencies are involved in biomass research and development.(16) Also, an independent non-governmental organization known as CBETS (Council of Biomass Energy Technology Sponsors) has been established to coordinate R&D activities among public and private sources.

TABLE 2-6

U.S. DEPARTMENT OF ENERGY FUNDING FOR BIOMASS ENERGY RESEARCH AND DEVELOPMENT, BY PROGRAM

($ millions)

	FY 1983*	FY 1984*	FY 1985
Production programs	4.0	7.7*	10.2*
Thermochemical conversion	5.0	7.8	11.2
Biochemical conversion	8.5	8.2	4.5
Regional programs	4.0	3.7	4.0
Other**	2.5	2.5	1.0

* Includes short rotation intensive culture.

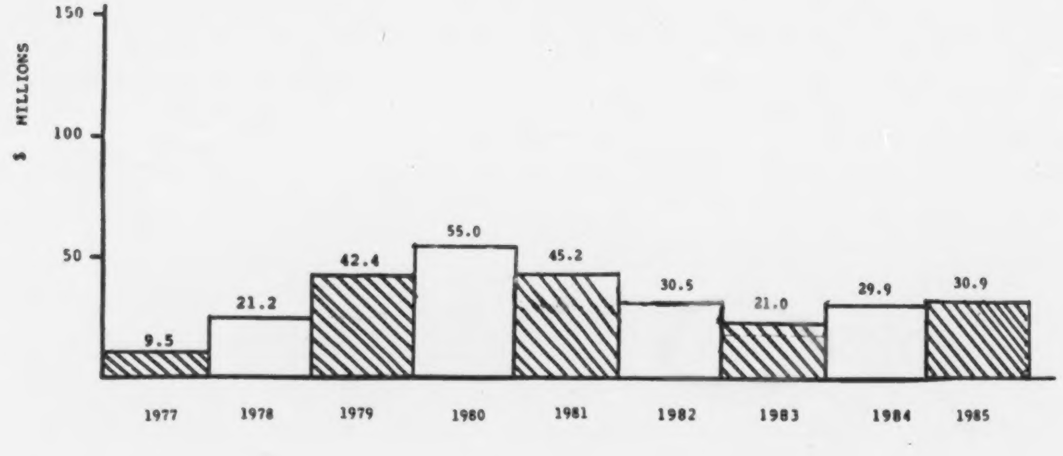
** Includes program planning, international cooperation, management support, technical and economic analysis and capital equipment.

Source: Department of Energy Fiscal Year Congressional Budget Request -- Energy Supply, Research and Development: Solar and Other Renewables. U.S. Department of Energy, Vol. 2, pp. 55-61.

Renewable Energy Technologies Program Summaries. Deputy Assistant Secretary for Renewable Energy, U.S. Department of Energy (DOE/CE-0105), November 1984, pp. 39-48.

FIGURE 2-5

U.S. DEPARTMENT OF ENERGY BIOMASS RESEARCH AND DEVELOPMENT FUNDING, FY 1977 - FY 1985*



* Until FY 1984, the U.S. Department of Energy had separate programs for alcohol fuels and biomass. The data in FIGURE 2-5 represent the sum of both programs.

The federal government provides a variety of financial incentives that support production of energy from biomass. DOE's Office of Alcohol Fuels administers a loan guarantee program totaling $225 million for assistance to ethanol production facilities. Tax incentives have been another form of support. A 10% federal business energy tax credit for investment in biomass energy equipment and facilities expired at the end of 1985. Also, a 6¢/gallon excise tax exemption is now available for 10% blended ethanol fuels. Domestic ethanol production is assisted by a 60¢/gallon import duty plus a 3% ad valorem tax levied on foreign ethanol.

State governments also support biomass energy technologies. As of 1984, 30 states were either funding biomass energy projects alone or in cooperation with other organizations.(6) In addition, 27 states and U.S. territories offer incentives for the development of gasification and wood and agricultural waste combustion systems; 30 have incentives for stimulating the production of alcohol fuels; and 17 have incentives to promote the development of refuse-to-energy systems (See APPENDIX I).

Finally, indirect support comes from the national Public Utility Regulatory Policies Act (PURPA) of 1978, which eases regulatory barriers for non-utility owned, independent electric power production from biomass resources. Biomass electric generators (under 80 MW) and cogenerators licensed as qualifying facilities with the Federal Energy Regulatory Commission (FERC) can sell their excess power to the local utility at that utility's avoided cost of generating or purchasing that same amount of power from conventional sources.

INDUSTRY STATUS

There is no single biomass industry. Instead, there is a mix of companies active in manufacturing and distributing the various biomass conversion systems, as well as those involved in resource preparation and utilization. This section will focus on those segments of the industry that can be identified with one or more type of particular biomass conversion system, and those involved in biomass resource development.

BIOMASS

Biomass Resource Development

Biomass resource development and processing represents a significant part of the U.S. biomass industry. Farm, seed, chemical and plant industries make investments in biomass feedstock production, however, most research is focused on developing high value specialty crops only few of which have an energy value greater than other potential markets. In the U.S. Department of Energy data base there are 11 companies and laboratories involved involved in wood crop research and development projects and 3 involved in harvesting and processing research and development.

Commercially available harvesting and processing equipment is offered by 12 companies and 13 offer fuel preparation (densification) systems. Herbaceous biomass research and development is being conducted by 13 organizations, and 11 are involved with aquatic resource development.(5) Many of the efforts are done cooperatively with the U.S. Department of Energy.

Residential Wood Combustion

The residential solid fuel industry is comprised of manufacturers and retailers of wood burning appliances, product suppliers, as well as service industries such as testing centers and chimney sweeps. Wood fuel system manufacturers are a well established industry numbering over 700 in 1984. The most common systems manufactured are wood stoves (39%), fireplace inserts (30%), central heaters (18%), manufactured fireplaces (9%), and cookstoves (4%).(35) Nearly 40% of all manufacturers make three or more solid fuels products. Most solid fuel industry manufacturers have a single manufacturing plant, with nearly half located in the North Central region of the U.S. Both New England and the Mid Atlantic states also contain a high concentration of the industry. The largest manufacturers (those producing 50,000 units or more annually) have been in business for over 25 years, while over three quarters of the manufacturers are less than 10 years old. With little government support for technology development, research and development spending by the industry accounts for 6% or more of revenues for many manufacturers.(34)

The component of the industry supplying products to manufacturers and system owners includes hundreds of companies offering almost as many products. These include system retrofits (e.g., heat exchangers, catalytic combustors, fans, stokers, thermostats and sensors, and water heaters), fireplace and chimney supplies (e.g., bellows, chimney liners, dampers, chimney caps, screens, grates, firebrick and other masonry, stove pipe, fireplace tools and cookware), and fuel preparation and handling accessories (e.g., axes, mauls, wedges, log splitters, wood carriers, storage bins, and pelletizers and other densifiers).

Service industries such as testing laboratories and chimney sweeps make up another important segment of the industry. In 1984, there were 19 independent testing laboratories evaluating system performance and emissions. Twenty six chimney sweep guilds or organizations with individual members numbering in the hundreds are distributed nationwide.(35)

Commercial and Industrial Wood Energy Conversion

The domestic industry involved in developing commercial and industrial thermochemical energy conversion systems include research and development projects, manufacturers, project developers, and end-users. Comprehensive data on all segments of this industry is not available, however, some segments can be quantitatively characterized. For direct combustion systems, often a multiple fuel boiler system will be employed. The multiple fuel boiler system (MFBS) industry is highly concentrated with 5 firms controlling 65% of the sales.(5) These five are the only firms producing all four types of MFBS components: fuel processing, handling and storage systems; steam generating equipment; and air pollution and waste disposal devices. The remaining 35% is controlled by many smaller firms all of which make various components going into a complete system. Based on a literature search conducted in the early 1980s, the number of manufacturers marketing thermochemical conversion equipment for wood are depicted in TABLE 2-7.

TABLE 2-7

NUMBER OF U.S. COMPANIES INVOLVED IN WOOD CONVERSION EQUIPMENT MANUFACTURING AND R&D

Conversion System	Single Wood Conv. Prod.	Multiple Wood Conv. Prod.	Equipment and R&D	R&D Only
Boilers	70	5	0	0
Burners	14	2	0	0
Incinerators	2	0	0	0
Dryers	0	2	0	0
Furnaces	9	1	0	0
Fluid Bed Comb.	5	3	1	0
Gasifiers	20	22	15	3
Pyrolyzers	2	15	3	2
Methanol	0	0	0	2
Other	0	0	0	3

Source: James L. Easterly (Meridian Corp.) and Elizabeth H. May (Science Applications International Corp.). Characteristics of the Industry Which Manufactures Wood Energy Conversion Systems (Draft). U.S. Department of Energy, June 1984, p. 13.

Waste-to-Energy

Energy from municipal solid waste (MSW) has become a growing segment of the biomass industry. Primarily licensing technologies from Europe, the industry began by focusing on large capacity projects, (on the order of 1000 tons/day or more) designing and building systems on-site to meet the needs of a large, proximal steam user. Since the designs were highly site-specific, complete systems were not available. The limited number of potential projects with adequate capacity has limited this component of the industry to less than 10 firms.(36)

A recent development that has emerged in the refuse-to-energy industry is the development of modular municipal solid waste-to-energy systems to meet the needs of smaller projects (on the order of 100 tons/day or less). Manufacturers began to offer complete factory built, skid-mounted and delivered systems. This is perhaps the fastest growing portion of the refuse-to-energy industry. Today, there exists 12 modular system vendors, 9 waterwall system vendors, 4 refractory system vendors, and 5 refuse derived fuel (RDF) system vendors.(36)(4) The solid waste management industry remains poised to adopt their well established infrastructure to this market.

Landfill Methane Gas

Another emerging segment of the industry recovers methane from closed municipal waste landfills. Originally, naturally generated methane was vented to prevent seepage into nearby residences. More recently, the systems have been optimized to produce high quality biogas for energy sales encouraging an increasing number of developers and engineering firms to become involved. Most projects include the participation of local or city governments, as well as the end-user (gas or electric utility, or industrial firm).

Anaerobic Digestion

The U.S. anaerobic digestion industry is in varying stages, with specific applications defining the level of industry involvement. There are about 15 companies that design and build digestors, primarily for domestic farm applications.(19) The most established segment of the anaerobic digestion industry uses digestors for sewage treatment. While the digestor is a vital component in the overall system, these applications have been primarily for waste stabilization, and only recently been involved with commercial production and sale of energy. Developers of these projects usually are architect/engineering firms with experience in adapting digestors for sewage treatment facilities.

Fermentation Ethanol

Over the past four years, ethanol has become a commercial scale, high-grade liquid fuel alternative in the U.S. During this time, the ethanol industry has developed an effective infrastructure of producers, distilleries and retailers. Currently, there appears to be no shortage of capable engineering, design and construction firms, as well as equipment manufacturers. The U.S. ethanol industry has grown remarkably since 1979, yet production barely exceeds half of available capacity (see TABLE 2-8).

TABLE 2-8
U.S. ETHANOL PRODUCTION AND CAPACITY
(million gallons/year)

Year	Production Capacity	Production	Percent
1979	60	20	33%
1980	180	40	22%
1981	380	75	20%
1982	595	210	35%
1983	700	375	54%
1984	840	434	52%

Source: Information Resources, Inc., Washington, DC.

Another important development in the U.S. ethanol fuels industry is the growing concentration in production. The bulk of today's production comes from less than 25 firms. In fact, one company accounted for 50 percent of 1984 production levels, and the next six largest companies provided another 40 percent. Only 58 out of 145 plants with annual capacities in excess of 500,000 gallons were in operation at the end of 1984.(19)

MARKET STATUS

The market for biomass energy is determined by availability of the various feedstocks, the commercial viability of specific conversion processes, and most importantly, the end-use market for the resulting biofuel. Market applications include the combustion of solid fuels for industrial processes and space heating, gasification and anaerobic digestion to replace natural gas, fermentation of grains for liquid transportation fuels, and many others. The status of the overall market for biomass energy is discussed for the entire process from resource to production to end use. Given the enormous possibilities, focus is given to existing conversion technologies and established markets in the U.S.

BIOMASS

Although the major thrust of current biomass usage is the conversion of existing wastes and surplus crops, biomass energy may ultimately depend on the cultivation of biomass resources expressly for energy. Therefore, the market potential for biomass energy could be much greater than the 3.0 - 3.5 quads or 5% of all energy now supplied in the U.S.(38) In many developing countries, biomass represents nearly half of all energy consumption, with some countries such as Ethiopia relying on wood and other biomass resources for 95%.(39)

Wood and Wood Waste Utilization

Direct combustion of wood is the most common biomass energy usage in the U.S., accounting for 95% of all bio-energy in 1984.(19) U.S. Department of Energy estimates of wood energy consumption amounted to 153 million short tons (139 million tonnes) in 1983 (the last year calculated) with the largest consumers being the residential sector (35%) and the industrial sector (64%).(37) This represents a 6% increase over 1982 levels. Since wood is both cumbersome to transport and store, usage has been limited to areas where availability is high or the additional cost of transportation is offset by savings over other fuels.

Residential combustion systems for solid biomass fuels, particularly wood, represents a well established market share in residential space heating systems. Approximately 20% of all U.S. homes now burn wood as a primary or supplementary source of heat.(6) According to the Energy Information Administration, wood represents the second most chosen fuel in houses that switched heating sources. Annual wood burning systems (fireplaces, woodstoves, fireplace inserts, and furnaces) installations total nearly 4 million units each year, however, the demand for residential systems declined slightly in 1984 (see TABLE 2-9).

TABLE 2-9

ANNUAL RESIDENTIAL WOOD BURNING SYSTEMS INSTALLATIONS

(thousands of units)

Year	Fireplaces	Wood Stoves	Inserts	Furnaces
1981	1,022	2,118	n.a.	n.a.
1982	1,120	1,757	831	185
1983	1,637	1,310	835	209
1984	506	1,181	758	154

Source: Installation of Fireplaces, Stoves and Inserts in New and Existing Houses. Housing Industry Dynamics, Inc., prepared for the Wood Heating Alliance, (1981-1984).

According to Housing Industry Dynamics, 61% of wood burners were sold east of the Mississippi. Also 53% of the stove buyers are between 25 and 35 years of age, probably because of the added effort required to operate a solid fuel heating systems.(46) The use of wood heating exclusively, however is likely to be limited to those people who consider this type of activity enjoyable or wish to use wood for some degree of self-sufficiency. Accompanying the growing number of households burning wood for energy is the concern over emissions of polycyclic organic matter, hydrocarbons, and carbon monoxide. Two states, Oregon and Colorado, as well as a number of local governments have addressed the problem through the establishment of standards, and other programs.(40) The Environmental Protection Agency is also considering the development of nationwide performance and emission standards for new stoves.

Industrial Wood and Wood Waste Utilization represents another significant market for biomass energy systems. Resource based companies, forest and agricultural products, are increasing their utilization of captive biomass resources and waste to improve the efficiency of their operations and contribute to on-site energy requirements. The wood products industries (paper products and wood and lumber products) are focusing efforts on increasing the amount of wood and wood waste they utilize in a variety of applications. The agricultural processors are also attempting to utilize their by-products and waste to produce fuels and thermal energy for internal processes. Both forest products and agricultural industries are increasing their use of biomass energy to generate electricity to meet on-site needs or for sale to a local utility. Other non-resource based industries such as textiles, furniture manufacturers, chemical companies, and glass and ceramic products that require heat in the preparation and treatment process can also use direct combustion and gasification of biomass. Energy from wood and wood waste now provides 8% of all energy consumed by the industrial sector in the U.S.(37)

The U.S. paper and allied products industry (SIC 26) is the largest domestic industrial biomass energy producer. According to the American Paper Institute, the industry self-generated 55.2% of its total energy requirements from residual biomass sources. The wood and lumber products industry (SIC 24) is responsible for about 25% of all industrial wood utilization for energy production.(37) The entire forest products industry expects to be able to supply 4 Quads of energy by the year 2000.(47) Decisions concerning the use of wood for energy by this industry are based on economics, attempting to maximize the value of that wood for other purposes first. For this reason, biomass energy will continue to come from waste sources such as hogged fuel, bark, sawdust, spent liquors, and other sources.

Waste-to-Energy

Energy from municipal solid waste (MSW) represents a growing market in the U.S. The value of these systems is attributed to the high cost of energy, the limited number of suitable disposal sites, and public opposition to sanitary landfills. For these reasons, the northeast, south, and the more urbanized states in the west (namely California) represent the fastest growing markets. The most established waste-to-energy technology is direct combustion of collected MSW for industrial process heat and electricity generation.

Industrial process steam represents the most desirable energy applications for *direct combustion waste-to-energy* projects as the demand is generally continuous and not subject to seasonal fluctuations.

However, potential industrial customers are often reluctant to enter into the long-term steam purchase contracts that are required for MSW project financing, due to potential fluctuations in industrial productivity and output. The market for steam plants is limited to about 20% of the available waste by market and economic conditions.(5)

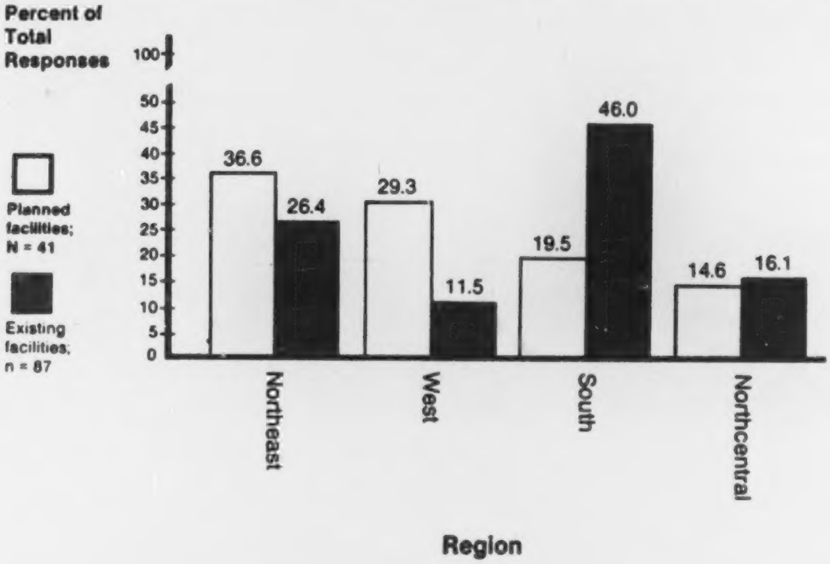
Electricity generation, as either the sole energy product or as part of a cogeneration scheme, provides an alternative market for MSW projects. Electric utilities can offer long-term power purchase agreements and easier siting requirements (access to the utility grid rather than a steam user). In fact, for small utilities (loads of less than 300 MWe or 300,000 customers) waste-to-energy represents the first overall choice for biomass projects built after 1990, according to the Electric Power Research Institute.(5)

According to the 1984 Resource Recovery Yearbook, there are 87 existing waste-to-energy facilities in the U.S. and an additional 41 in some stage of construction or planning.(25) The Northeast and South account for nearly three quarters of the existing facilities, however, activity is increasing in California and other western states (see FIGURE 2-6). While steam represents the overwhelming fuel yield of existing facilities, electricity production seems the future market for waste-to-energy projects (see FIGURE 2-7). Current facilities utilize only 1-2% of the total MSW available in the U.S. for energy production.(23)

The future market for waste-to-energy facilities seems encouraging. There are 124 U.S. recovery plants in the conceptual stages of planning. California is the state with the highest number of planned projects, representing over 12% of the total.(25) For new waste-to-energy projects, the market appears to be changing to include more modular MSW facilities along with large site-built systems. Over 90% of total installed capacity from modular MSW systems has been constructed or installed since 1980 (see TABLE 2-3).(4)

FIGURE 2-6

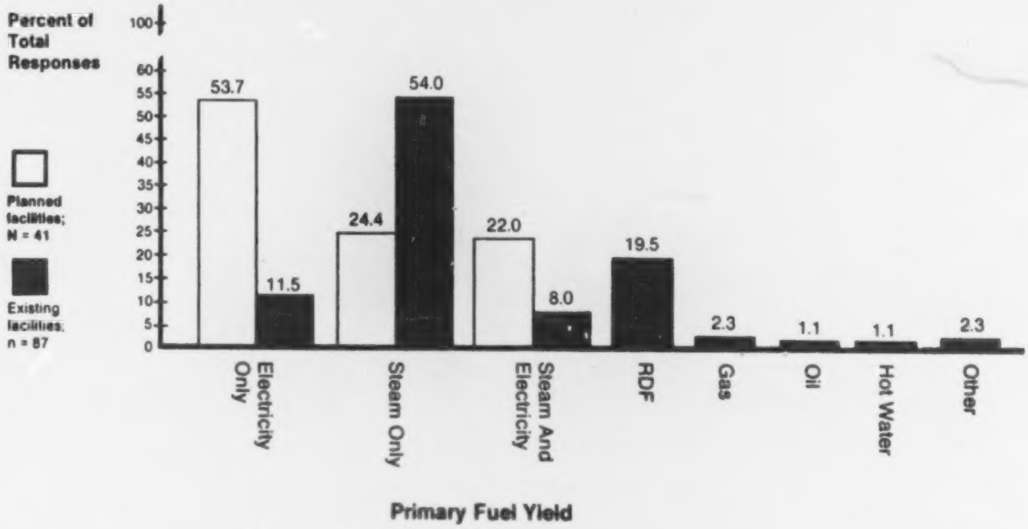
NUMBER AND LOCATION OF WASTE-TO-ENERGY PLANTS BY REGION, 1984



Source: The 1984 Resource Recovery Yearbook. New York: Government Advisory Associates, Inc., 1984, p. 18.

FIGURE 2-7

PRIMARY FUEL YIELD OF WASTE-TO-ENERGY FACILITIES, 1984



Source: The 1984 Resource Recovery Yearbook. New York: Government Advisory Associates, Inc., 1984, p. 30.

Landfill Methane Gas

Landfill methane from municipal solid waste (MSW) represents another sizable and growing bio-energy market. The total number of operational and planned landfill methane recovery projects producing high-BTU or medium-BTU gas is about 50.(40) Existing facilities in the U.S. produce almost 5 trillion BTUs in heating value, not including methane used for electricity generation. This represents only 0.5% of the total landfill methane available in the U.S.(6) High-BTU facilities are of special interest to the natural gas industry as a supplement to their regular sources of supply. There are 8 operating high-BTU facilities and at least 9 projects in some stage of planning.(33) Medium-BTU facilities serve the industrial sector with some output going to electricity production. There are 22 existing facilities producing medium-BTU gas and an additional 10 or more in some stage of planning.(40)(33) Over half of the existing landfill methane gas recovery projects are located in California.(40) TABLE 2-10 indicates the estimated landfill gas production.

TABLE 2-10

ESTIMATED ANNUAL LANDFILL GAS PRODUCTION IN THE U.S.

Year	High-BTU* (Billion ft^3)	Medium-BTU** (Billion ft^3)	Total Heating Value (Trillion-BTU)
1980	.4	.6	.7
1981	.8	.7	1.1
1982	1.4	2.1	2.4
1983	2.6	2.8	4.0
1984	2.7	4.0	4.7

* Assumes 1000 BTU/ft^3.
** Assumes 500 BTU/ft^3.

Note: Does not include gas produced for electric generation.

Source: Jeffery L. Wingenroth and Margaret N. Davis (American Gas Association), "Status of Landfill Methane Recovery Projects", Gas Energy Review, Dec. 1984, p. 16.

Anaerobic Digestion

Anaerobic digestion of municipal sewage and animal wastes represents another potentially significant market. The treatment of municipal sewage and disposal of sludge resulting from conventional sludge or trickle systems represents one of the major energy users (second to streetlights) and cost elements in today's cities.(9) Anaerobic digestors are used to help stabilize wastes and meet on-site energy requirements and are generally not devoted to production of methane for commercial use.

Much of the biogas is used to heat the digestor bed, and the excess is flared.(12) The current value of such systems is determined by the displacement of conventional energy sources used in the sewage treatment process.

On-farm anaerobic digestors have not reached the same level of penetration here in the U.S. as they have in many developing countries. The potential of U.S. animal feedlot applications would produce more biogas than can be used on-site, and due to the low quality of the gas (high CO_2 content), transporting it is uneconomical. At the end of 1983, 46 anaerobic digestion facilities were producing methane from manure, food processing wastes, and chemical wastes.(19) A more recent unreleased study by the Solar Energy Research Institute (SERI) indicated that 50 U.S. farms are outfitted with commercial organic waste to biogas facilities.(19)

Other countries are more active than the U.S. in the anaerobic digestion technology. Brazil has used the technology to convert alcohol stillage from 50 of its ethanol facilities. Before 1979, there were 6.5 million digestors installed in China producing 700 million cubic meters of biogas annually. Since then, another 3 million units of more modern design have been installed, 95% of which are still operating today. Installations still average 600,000 units per year.(19) India also has significant anaerobic digestion penetration with over a quarter of a million installations so far. The fact that it is economical and socially accepted in other countries, where labor costs and standards of material comfort are much lower, does not imply that comparable technologies will enjoy the same penetration levels in the U.S. For the near future, this market in the U.S. will be limited and most of the foreign market will be supplied by simple, low-cost, designs.

Electricity Generation

In recent years, electricity generation from biomass sources has increased; total installed generating capacity reached 1,812 MWe in 1984.(23) Including projects planned or under construction, the market for biomass electric systems totaled 3660 MW.(23) This represents a variety of conversion technologies and resources, and includes the participation of utilities, private industry, independent developers, and municipalities (see TABLES 2-11 and 2-12). The enactment of PURPA (see GOVERNMENT SUPPORT) has encouraged the involvement of non-utility parties in biomass to electricity projects, now accounting for 93% of the total number and total generating capacity of projects that are operating, planned, or under construction.

One reason that utilities have not been eager to embrace biomass as a source of fuel for electricity generation is a concern that feedstock prices could rise unbearably after a relatively expensive facility had been constructed.(5) Where resources are plentiful and have no competing markets, such as the 184 MWe of bagasse (sugarcane residue) fueled capacity in Hawaii, utility participation may be greater. Also, as non-utility use of these resources and technologies increases, electric utilities are more likely to view biomass as a viable source of power. An area of growing interest is the retrofit of biomass gasifiers to diesel generators.

TABLE 2-11

BIOMASS-FUELED SMALL POWER PRODUCTION CAPACITY BY FUEL TYPE in Kilowatts (Number of Facilities)

FUEL	PLANNED	UNDER CONSTRUCTION	OPERATING	TOTAL
Wood Waste	304,475 KW (21)	214,820 KW (18)	1,092,597 KW (59)	1,611,892 KW (98)
Agricultural Residues	152,600 KW (4)	56,000 KW (3)	144,050 KW (8)	352,650 KW (15)
Animal Manure	94,000 (2)	10 KW (1)	1,225 KW (3)	95,235 KW (6)
SUBTOTAL	551,075 KW (27)	270,830 KW (22)	1,237,872 KW (70)	2,059,777 KW (119)
Municipal Solid Waste	541,550 KW (25)	335,300 KW (11)	350,410 KW (18)	1,227,260 KW (54)
Landfill Methane	52,925 KW (18)	24,850 KW (16)	40,565 KW (19)	118,340 KW (53)
Sewage Methane	164 KW (2)	2,700 KW (1)	6,720 KW (4)	9,584 KW (7)
SUBTOTAL	594,639 KW (45)	362,850 KW (28)	397,695 KW (41)	1,355,184 KW (114)
TOTAL	1,145,714 KW (72)	633,680 KW (50)	1,635,567 KW (111)	3,414,961 KW (233)

TABLE 2-12

UTILITIES USING BIOFUELS: STATUS BY FUEL TYPE in Kilowatts (Number of Facilities)

FUEL	PLANNED	UNDER CONSTRUCTION	OPERATING	TOTAL
Wood Waste	50,000 KW (1)	—	130,725 KW (8)	180,725 KW (9)
Agricultural Residues	—	—	22,500 KW (2)	22,500 KW (2)
Animal Manure	—	—	—	—
SUBTOTAL	50,000 KW (1)	—	153,225 KW (10)	203,225 KW (11)
Municipal Solid Waste	—	18,400 KW (2)	15,400 KW (3)	33,800 KW (5)
Landfill Methane	—	—	—	—
Sewage Methane	—	—	7,970 KW (2)	7,970 KW (2)
SUBTOTAL	—	18,400 KW (2)	23,370 KW (5)	41,770 KW (7)
TOTAL	50,000 KW (1)	18,400 KW (2)	176,595 KW (15)	244,995 KW (18)

Source: James L. Easterly (Meridian Corp.) and Elizabeth H. Saris (Science Applications). Electric Power from Biofuels. U.S. DOE (DE-AC01-83CE-30784), January 1985, pp. 18 and 9.

Fermentation Ethanol

The fermentation ethanol market, which is closely tied to government support programs, was encouraging in 1984 and should continue through 1988 (the year EPA has designated for complete lead phase-out in gasoline). Ethanol is a leading candidate to replace lead as an octane enhancer. Fuel ethanol blend (10% ethanol in gasoline) sales, the largest market for ethanol, reached 5,675,460 gallons in 1984, a 25% increase over 1983.(21)

TABLE 2-13

U.S. FUEL ETHANOL/GASOLINE BLEND SALES AND MARKET PENETRATION

(gallons)

Year	Ethanol Blend Sales	Percent of Gas Market
1981	812,592	n.a.
1982	2,306,100	2.3%
1983	4,333,904	4.2%
1984	5,675,460	5.6%

Source: Alcohol Outlook, Information Resources, Inc., Washington, DC, March 1985, p. 2.

D.L. Klass, "Energy from Biomass and Waste: 1984 Update", Institute for Gas Technology.

Although ethanol blended gasoline is now sold in 43 states, the majority of the market is concentrated in 10 states responsible for 80% of 1984 sales. Although penetration of ethanol blends amounted to 5.6% of the nation's gasoline market, it reached 20% or greater in several Midwestern states (Iowa: 34%, Nebraska: 29%, Kansas: 23%, Indiana: 20%, and Kentucky: 20%).(21) It should be noted that all five states offer gasoline tax exemptions for ethanol blends, as well as having an agricultural base for ethanol feedstock grains (see RESOURCE AVAILABILITY and APPENDIX I).

The primary feedstock for ethanol production in the U.S. was corn, comprising over 50% of the total in 1984 (see TABLE 12). The use of corn has increased from 16 million bushels in 1980 to 175 million in 1984.(18)

This trend should continue as the National Corn Growers Association has identified ethanol as a major market for its 1984 billion bushel surplus. Nonetheless, most industry analysts foresee ethanol from cellulosic feedstocks (e.g., wood wastes, crop residues, municipal solid waste) providing the long-term market opportunities due to better resource availability.

TABLE 2-14

1984 FEEDSTOCKS FOR U.S. ETHANOL PRODUCTION

Feedstock	Percent of Total
Corn	54%
Other grains	22%
Molasses	13%
Food Waste	11%
TOTAL	100%

Source: Information Resources, Inc., Washington, DC.

Imports in 1984 amounted to 170 million gallons of anhydrous ethanol, a 67% increase over 1983. Brazil captured 80% of this market by exporting 137 million gallons of anhydrous ethanol to the U.S. market.(21) Other major sources of imports included the United Kingdom, Canada, Argentina, Spain, France, and South Africa.

The U.S. market continues to look promising as major government policies take shape. Industry analysts expect U.S. ethanol production to reach 600 million gallons in 1985 and 800 million gallons in 1986. The cause for such optimism is attributed to an increase in Federal gasoline tax exemption and import tariffs (see GOVERNMENT SUPPORT).

More important still is an EPA ruling on lead in gasoline. Beginning in 1985, refiners must reduce lead content in gasoline from 1.1 to 0.5 grams per gallon. This will be further reduced to 0.1 grams per gallon by January 1, 1986. The effect of this ruling is already having its impact as hundreds on blenders have registered with the EPA to "bank" and sell lead rights (0.5-4.5¢/gram of lead rights) to refiners who are unable to meet EPA's restrictions and deadlines. It is important to note, however, that ethanol is not the only proposed lead substitute in gasoline. Methanol, benzene, xylene and others will be competing for this growing market.

The international market is also expected to grow. A very substantial market and industry already exists in Brazil as a result of that government's establishment of the National Alcohol Program (NAP). Total production for 1984 was roughly 2.5 billion gallons of anhydrous ethanol which represents about 75-85% of total production capacity.(19) In fact, Brazil's annual increase in consumption is the equivalent of building an industry the size of the present one in the U.S. every year. Today Brazil has nearly 10 million vehicles running on either straight or blended ethanol.(19) Many other countries have or are establishing ethanol industries including the U.K., Canada, Argentina, Spain, France, South Africa, Netherlands, West Germany, Yugoslavia, Norway, Japan, China, Korea, Mexico, and Sweden.

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Chapter 3

GEOTHERMAL

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GEOTHERMAL

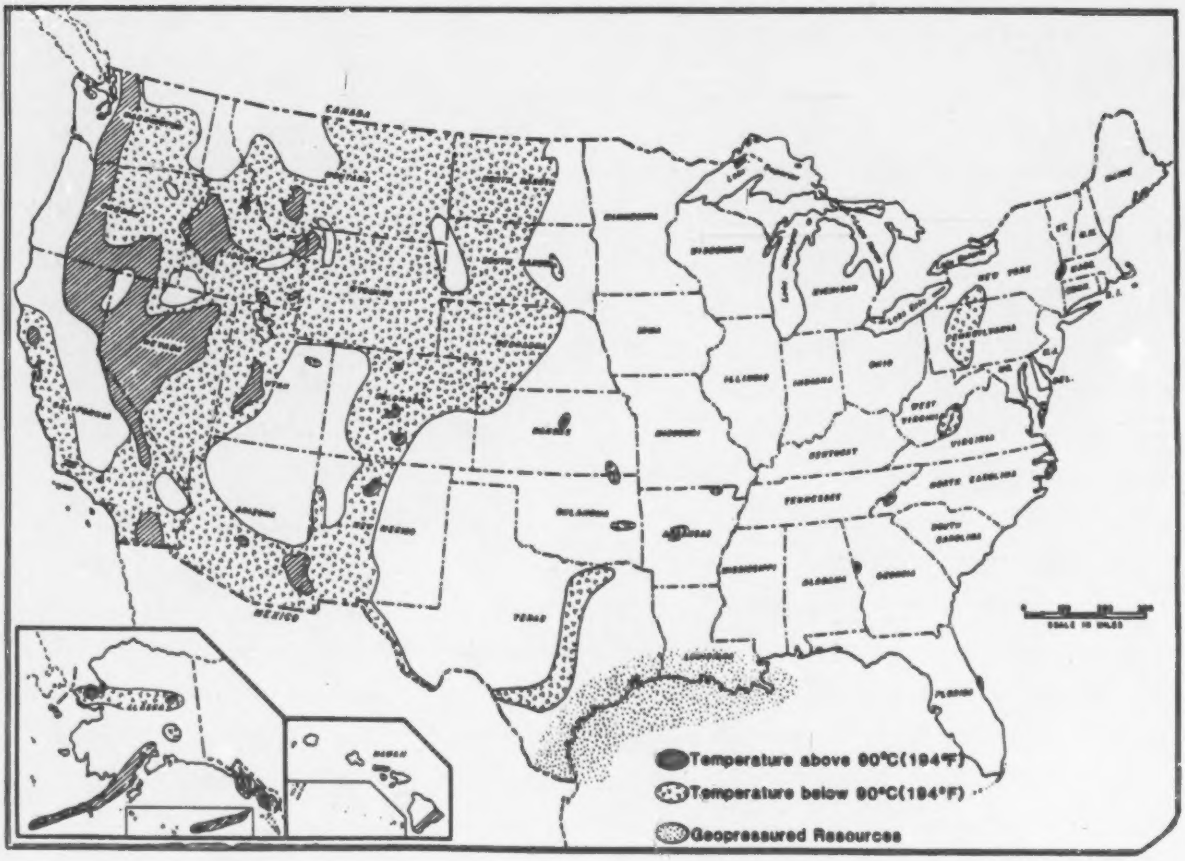
RESOURCE AVAILABILITY

Geothermal energy is the natural heat generated from within the earth. Underneath the earth's relatively thin crust, temperatures range from 1800° to 7200°F (1000° to 4000°C) and, in some areas, pressures exceed 20,000 pounds per square inch (psi). Geothermal energy is most likely generated from radioactive thorium, potassium, and uranium dispersed evenly throughout the earth's interior which produce heat as part of the decaying process. This process generates enough heat to keep the core of the earth at temperatures approaching 7200°F (4000°C). Composed primarily of molten nickel and iron, the core is thought to be surrounded by a layer of molten rock, the mantle, at approximately 1800°F (1000°C).(10) Nine major crustal plates float on the mantle, and currents in the mantle cause the plates to drift, colliding in some areas and diverging in others. When two continental plates converge, a complex series of chemical reactions involving water and other substances combine to generate large bodies of molten rock called magma chambers that rise through the crust, often resulting in volcanic activity. Molten rock also rises in the earth's crust where the plates are moving away from each other, and in other areas where the crust is thin. Volcanoes, hot springs, geysers, and fumaroles are natural clues as to the presence of geothermal resources near the surface, and perhaps where economic drilling operations can tap their heat and pressure. Additional heat can be generated by friction as two plates converge and one moves on top of another.(10)

The U.S. has an estimated 1.2 million quads (quadrillion BTUs) of accessible geothermal resources under 3.4 million acres of land (1.4 million hectares), mostly within the western third of the country.(23) About 10% of the world's land mass contains accessible geothermal resources that could provide several million quads of energy annually (see FIGURE 3-1).(27)

FIGURE 3-1

KNOWN AND POTENTIAL GEOTHERMAL RESOURCES IN THE U.S.



Source: University of Utah Research Institute, Earth Sciences Laboratory, for the U.S. Department of Energy, 1985.

Major geothermal resources are often found at the edge of large continental plates, particularly in zones of collision or separation from another plate. Four areas offer significant promise: 1) the "ring of fire", so named because of its volcanic activity, including western South America, Central America, the western U.S. (including Alaska and Hawaii) Japan, Mexico, the Philippines, Indonesia, and New Zealand; 2) the Rift Valley in east Africa; 3) areas around the Mediterranean; and 4) the area where the mid-Atlantic ridge breaches the ocean surface, as in Iceland.(10) TABLE 3-1 indicates the resource potential for specific countries.

TABLE 3-1

ESTIMATES OF WORLDWIDE GEOTHERMAL ELECTRIC POWER CAPACITY POTENTIAL

(in Megawatts)

Country	MWe	Country	MWe
Argentina	19,950	Kenya	79,450
Bolivia	63,100	Korea (N. & S.)	79,450
Cameroon	15,150	Mexico	257,050
Canada	446,700	Morocco	19,950
Chile	30,200	New Guinea	30,900
China	537,050	New Zealand	30,900
Columbia	77,650	Nicaragua	33,900
Costa Rica	12,600	Peru	302,000
Ecuador	100,000	Philippines	67,600
El Salvador	5,000	Portugal	1,000
Ethiopia	154,900	Saudi Arabia	15,850
Greece	8,900	Soviet Union	239,900
Guadeloupe	387	Spain	5,900
Honduras	12,600	Taiwan	8,150
Iceland	22,900	Tanzania	6,200
India	15,200	Turkey	87,100
Indonesia	436,500	U.S.	501,200
Iran	75,850	Venezuela	39,800
Italy	33,900	Vietnam	37,150
Japan	79,450		

Source: Electric Power Research Institute (1978), as cited in U.S. Geothermal Technology: Equipment and Services for Worldwide Application, U.S. Department of Energy/ID-10130, 1985, p. 4.

There are four types of geothermal resources: hydrothermal, geopressured, hot dry rock, and magma.

- *Hydrothermal* resources contain superheated water, steam or both in fractured or porous rock trapped by a layer of impermeable rock. The highest quality reserves contain steam with little or no condensate (vapor-dominated resources). Some hydrothermal reserves are very hot, but roughly two-thirds are of moderate temperature (150° to 250°F).(23) Only two sizable, high-quality dry steam reserves have been located to date, one in the U.S. and one in Italy.(15) The Geysers, in northern California, is perhaps the world's largest dry steam field and could provide 2000 MWe of capacity for up to 30 years.(34). In the U.S., potential hydrothermal resources may be found in

Wyoming, Nevada, Oregon, Alaska, Utah, Idaho, New Mexico, Arizona and Hawaii.(23)(34) All told, hydrothermal reserves account for approximately 3.8% of the accessible geothermal resources underlying the U.S.(23)

- *Geopressured* resources contain moderate-temperature brines containing dissolved methane. They are trapped under high pressure in deep sedimentary formations sealed between impermeable layers of clay and shale. Pressures vary from 5,000 to over 20,000 psi at depths of 5,000 to 50,000 feet (1500 to 15,000 meters).(20)(10) Temperatures range from 200° to over 400°F (90°-200°C), although they seldom exceed 300°F (150°C).(10)(28) Each barrel of fluid at 10,000 psi and 300°F could contain between 20 and 50 standard cubic feet (SCF) of methane.(10)

  Geopressured reserves are rare. In the U.S., they are predominately found along the Texas and Louisiana Gulf Coast. In the Gulf of Mexico, geopressured reserves cover an area as large as 100,000 square miles and contain between 3,000 and 30,000 trillion cubic feet (Tcf) of natural gas.(28) Accessible reserves are between 50 and 5,000 Tcf.(12) Geopressured reserves are now of most interest for their methane content, although modest amounts of heat and hydraulic pressure can also be tapped. Thermal resources from geopressured reserves are considered marginal compared to other geothermal resources. The pressure is of primary use in eliminating the need for pumping to recover the fluids at high rates.(28)

- *Hot dry rock* resources contain high temperature rocks (above 300°F, or 150°C) that may be fractured and contain little or no water. The rocks must be artificially fractured and a heat transfer fluid circulated to extract their energy. Hot dry rock resources are much more extensive than hydrothermal or geopressured, but extracting their energy is more difficult. As much as 95,000 square miles (246,050 km^2) of the western states have hot dry rock potential at a depth of 16,400 feet (5 kilometers).(10)

- *Magma* is molten rock at temperatures ranging from 1260°F to 2880°F (700°C to 1600°C). Lying under the earth's crust, the molten rock is part of the mantle and is approximately 15 to 30 miles (24 to 48 km) thick. Magma chambers represent a huge energy source, the largest of all geothermal resources, but they rarely occur near the surface of the earth and extracting their energy is difficult.

TECHNOLOGY DESCRIPTION

Geothermal energy is derived by using the earth's natural fluids to extract thermal energy that can be sent through a turbine to generate electricity or be used directly, e.g., district heating and industrial process heat. Conventional oil and gas drilling methods are primarily used to extract geothermal resources, using harder drill bits to combat corrosion and high temperatures.

Geothermal resources can be applied directly, usually using shallow wells and lower temperature heat (less than 350°F).(31) Heat exchangers can be used to transfer the heat from geothermal fluids to industrial process heat (IPH) applications. Because it is uneconomical to transport the thermal energy long distances, the end-use is often located nearby the resource.

To generate electricity, several types of systems can be used: direct steam, single and dual flash, binary, total flow, or a combination of these systems, referred to as *compound* or *hybrid* systems.

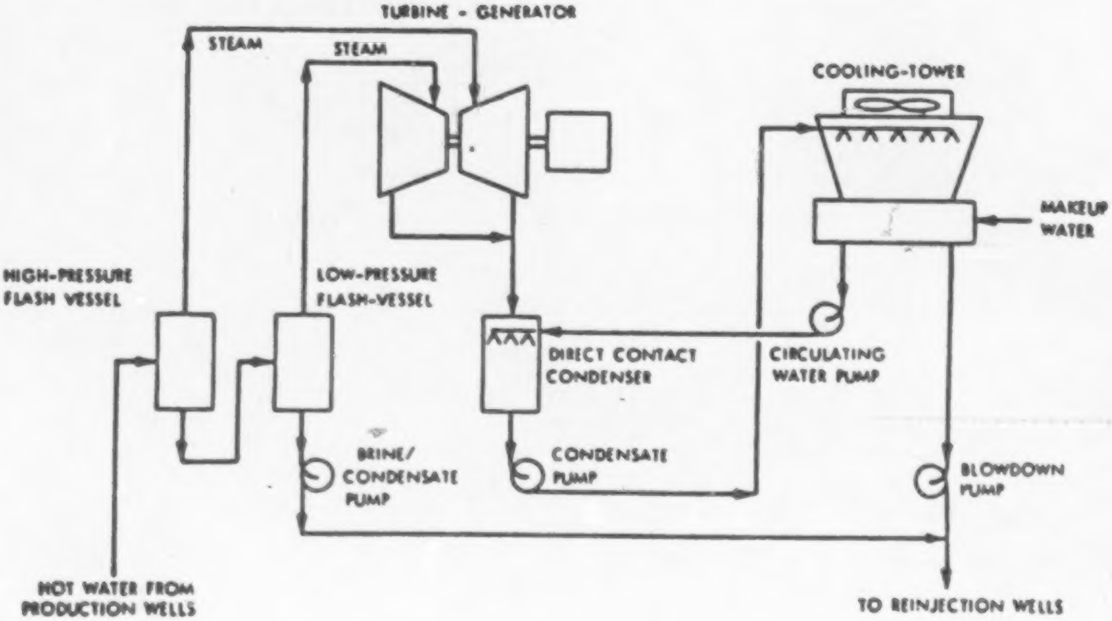
- *Dry Steam* systems extract the steam from wells and pipe it directly to a steam turbine.
- *Single Flash* systems flash evaporate hot geothermal fluids into steam, and direct it through a turbine. The remaining brine is reinjected into the reservoir.
- *Dual Flash* systems produce steam in two stages to extract more energy from the geothermal resource. Geothermal steam is separated from hot water and is fed directly into a dual inlet turbine, while the remaining water is flashed into steam in a low pressure vessel that is then directed through the turbine. The remaining hot water is reinjected into the ground (see FIGURE 3-2).
- *Binary* systems avoid corrosion and scaling problems associated from flash evaporating geothermal fluids by using a heat exchanger to transfer heat to a working fluid in a closed cycle system. The geothermal fluids are usually pumped from the reservoir and then reinjected into the ground while the working fluid is vaporized to power a turbine (see FIGURE 3-3). Binary cycle plants can be designed in a variety of ways to capture as much heat as possible.(29) The working fluid can be vaporized in stages

at different pressures and temperatures to extract more heat from the geothermal water. Heat from the working fluid condenser can be captured to vaporize a second working fluid for more generating capacity.

- *Total flow* systems are so called because they use the steam, hot water, and pressure of geothermal resources — the total resource. These systems usually channel geothermal steam into a steam turbine and capture the kinetic energy of the rapidly flowing fluids to spin a shaft to power a hydraulic turbine.

FIGURE 3-2

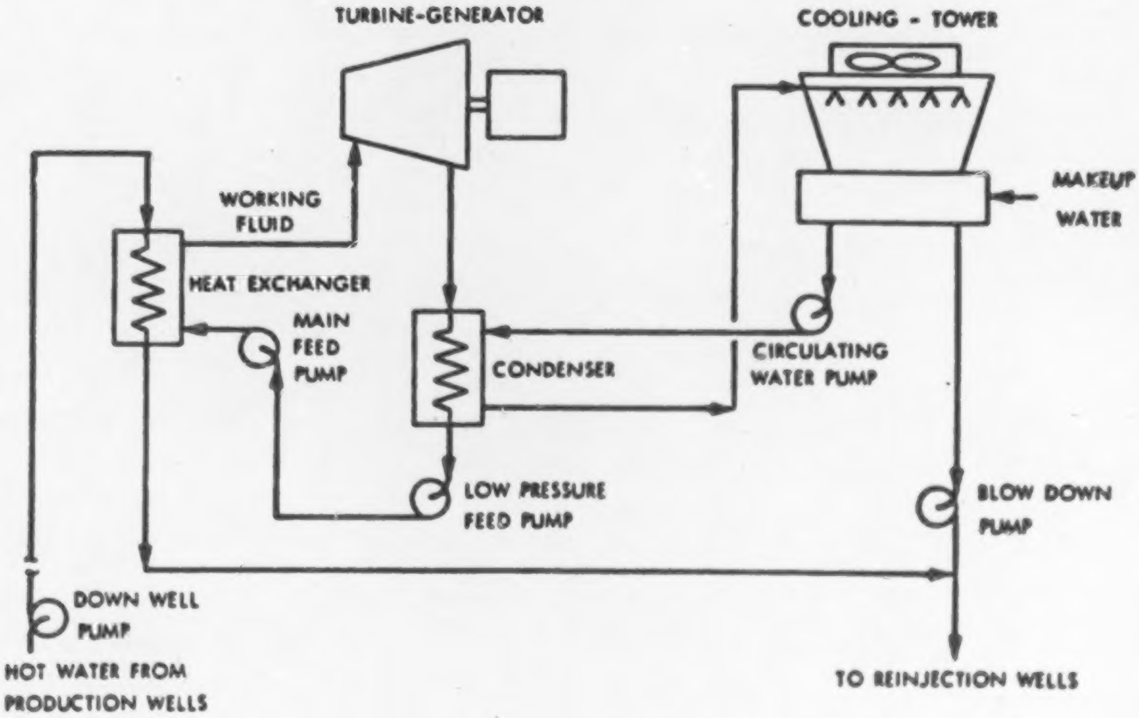
DUAL FLASH SYSTEM


TURBINE - GENERATOR
STEAM
STEAM
COOLING-TOWER
MAKEUP WATER
HIGH-PRESSURE FLASH VESSEL
LOW-PRESSURE FLASH-VESSEL
DIRECT CONTACT CONDENSER
CIRCULATING WATER PUMP
BRINE/ CONDENSATE PUMP
CONDENSATE PUMP
BLOWDOWN PUMP
HOT WATER FROM PRODUCTION WELLS
TO REINJECTION WELLS

Source: Commercial Status of Electrical Generation Technologies. California Energy Commission (P300-85-003), June 1985, p. 132

FIGURE 3-3

BINARY CYCLE SYSTEM


TURBINE-GENERATOR
COOLING - TOWER
MAKEUP WATER
WORKING FLUID
HEAT EXCHANGER
MAIN FEED PUMP
CONDENSER
CIRCULATING WATER PUMP
LOW PRESSURE FEED PUMP
BLOW DOWN PUMP
DOWN WELL PUMP
HOT WATER FROM PRODUCTION WELLS
TO REINJECTION WELLS

Source: Commercial Status of Electrical Generation Technologies. California Energy Commission (P300-85-003), June 1985, p. 135.

APPLICATIONS

Low-to-moderate temperature geothermal energy can be used to provide *domestic space and water heat* in such uses as a central heating system (district heating), or to supply space and water heating for individual residences, public institutions (e.g., schools, churches, hospitals), commercial buildings, and residential and commercial greenhouses. Geothermal fluids can also be used directly, for spas, and baths.

Geothermal fluids can be also used to provide heat for *industrial processes* like chemical production and cooking. The specific process application is determined by the nature and temperature of the geothermal resource. Geothermal heat or steam has been used to process food and other consumer goods, heat cattle barns, greenhouses, and fish ponds; dry food crops (e.g., onions and potatoes) and timber, assist digestion and distillation of ethanol, heat anaerobic digesters at wastewater treatment plants, and many other applications.(2) In addition, geothermal pressure can be used to directly power industrial processes. It can also provide hydraulic power or turn shafts to provide mechanical energy.

The primary use of geothermal resources has been for *electricity generation*. Such electricity can be fed into the utility grid, or it can be used to power industrial processes on site. Since the geothermal resource is constant (i.e. does not encounter daily or seasonal fluctuations), utility use of geothermal energy can be used for baseload power production or as a low-cost peak-load facility.

Methane from geopressured resources can be burned to superheat geopressured water to drive steam turbines more efficiently, or it can be used directly in chemical processes. Geothermal fluids contain many different metals, including potash, silver, borax, lead, zinc, and lithium. It has been suggested that these be recovered to provide additional revenues.(10)

Geothermal energy can be used in *aquaculture* to grow shrimp, tropical fish, catfish, and other warm water fish.

TECHNOLOGY STATUS

Direct Use

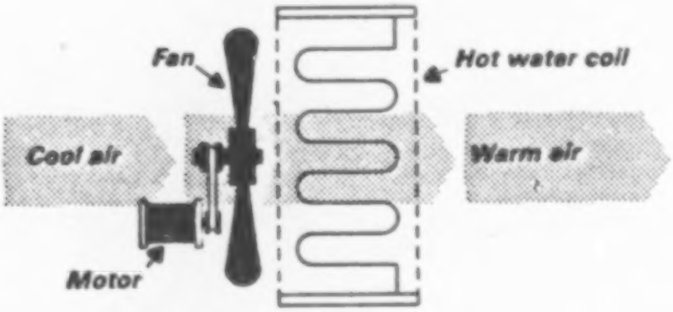
Geothermal resources have a long history of *direct use* application. The Romans and the Japanese bathed in geothermally heated pools 2000 years ago, while residents of Iceland cooked using geothermal heat in the 9th century. Several European towns relied on geothermal district heating in the Middle Ages.

These relatively simple applications are still popular today. About 100 million people visit the 1,500 hot spring resorts in Japan every year. In some regions of Mexico, people wash clothes with hot water from geothermal sources, while residents of Thailand and Guatemala boil vegetables with it.(17)

Direct use applications of geothermal energy usually use lower temperatures (50°-300°F, or 10°C-149°C), lower heat content, and shallower geothermal resources than electricity-generating applications. Direct use geothermal systems also do not require the high volume rates of fluid production of electricity-generating systems. Direct use systems can range in complexity from a fan-driven air heater, where cool air is blown over geothermally-heated hot water coils (see FIG. 3-4), to systems that transport geothermal fluids through several processes at varying temperatures. Generally, direct use geothermal systems provide heat or hot water through heat exchangers, although the resource can be used directly if its solids content is low.

FIGURE 3-4

FAN-DRIVEN AIR HEATER



Source: United States Geothermal Technology: Equipment and Services for Worldwide Applications. U.S. Department of Energy (DOE/ID-10130), 1985, p. 28.

GEOTHERMAL

Depending on the temperature of the resource, direct use geothermal can be used for a variety of applications (see FIGURE 3-5). Low-temperature resources (<100°F, or <38°C), for example, are ideal for aquaculture, while high temperature resources (>200°F, or >93°C) are well suited for cement drying and organic chemical processing. Presently, there are approximately 260 direct use geothermal projects in the U.S. that account for an estimated 1,860 billion BTUs annually. Some of the major uses of direct use geothermal in the U.S. are space and water conditioning, district heating, greenhouses, industrial processes, and aquaculture.

- *Space and water conditioning* are among the biggest consumers of direct use geothermal. Hospitals, schools, churches, and individual residences have all taken advantage of this type of direct use geothermal.

- *District heating* systems are another consumer of direct use geothermal. The oldest system is the Boise Warm Springs Water District in Boise, Idaho, that commenced operations almost 100 years ago. A newer district heating system nearby provides space and water heating to 20 government, institutional, and commercial buildings.

- *Greenhouses* rely on direct use geothermal to extend growing seasons and to reduce fuel costs. Perhaps the best known system in the U.S. is outside Susanville, California, where 31 greenhouses are heated using geothermal resources. Although temperatures outside can drop to -20°F (-29°C), the greenhouse can be kept at 70°F (21°C).

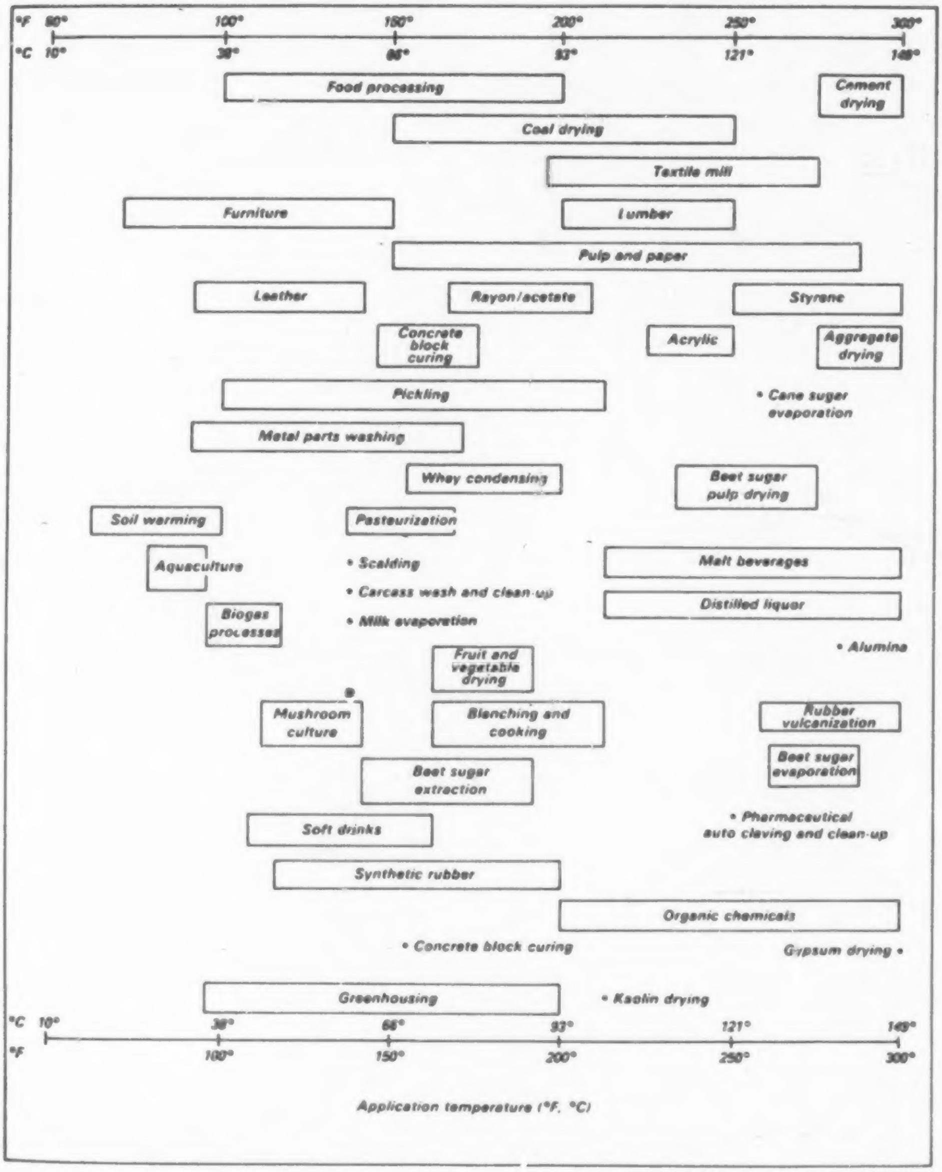
- *Aquaculture* facilities not only can extend growing seasons through direct use geothermal, but they can accelerate growing cycles and increase the size of mature fish. Warm water tilapia, catfish, and prawns reach maturity in 1/2 the time and are larger than those raised in colder water. Furthermore, direct use geothermal can allow the commercial raising and harvesting of fish that otherwise would not be possible, due to cold climates and short growing seasons. A good example is the fish hatchery in Buhl, Idaho. Channel catfish are raised in geothermal waters cooled to 27-29°C from spring and stream waters.

- *Industrial process heat* applications usually demand the highest temperatures (>150°F, or >66°C) of all geothermal direct use applications. Lower temperatures can be used, however, for various applications like drying and washing. Industrial process heat systems are not significant in actual numbers because of the problems in locating or relocating commercial facilities to geothermal sites. One such system, though, is a wastewater treatment plant in San

Bernandino, California, that processes almost 19 million gallons (81 million liters) of domestic and industrial waste a day.

FIGURE 3-5

DIRECT USE APPLICATION TEMPERATURES



Source: United States Geothermal Technology: Equipment and Services for Worldwide Applications. U.S. Department of Energy (DOE/ID-10130), 1985, p. 31.

GEOTHERMAL

Electricity Generation

Geothermal resources were first used for *electricity generation* in 1904 when Prince Piero Ginori Conti of Italy drove a simple single-cylinder steam engine with natural steam from shallow geothermal wells to provide electricity for a boric acid factory. By 1912, a 250 kWe system with a turbogenerator was operating in the dry steam fields in Larderello, Italy.(15) Development continued at Larderello; 130 MWe of capacity was installed by 1940. It was not until 1958 that the world's second geothermal project began generating power, the Wairakei power project in New Zealand.(2) The first project in the U.S., at the Geysers, in California, began operating in 1960, producing 12 MWe. By 1973, 441 MWe had been installed. The energy crisis of the 1970s sparked interest in geothermal energy around the world and development and exploration expanded.

Today, geothermal resources are located using several techniques derived from the oil and gas industry, including geologic maps, gravity meters to assess the density of the rock, drilling shallow holes to perform temperature and heat flow experiments, geochemical thermometers to measure the temperatures of chemical elements in hot springs, and measuring how electricity and sound waves travel through geologic formations.(20)

Several aspects of geothermal resources have slowed the development of geothermal energy. First and foremost, conventional oil and gas drilling methods predominantly used in extracting geothermal energy cannot economically tap deep resources such as hot dry rock and magma resources. Furthermore, the hard and abrasive nature of the formations where these resources are located, in addition to their high temperature and salinity, increase the possibility of corrosion and degradation of ordinary drilling equipment. Further improvements in drill bits, drilling fluids, and pipe and casing materials are needed.(4)(5)(31)

Most of the technologies for extracting geothermal resources have developed around hydrothermal resources used for electric power generation. The commercial installations, and most of the research and development work have centered around this resource. The other technologies for exploiting geopressured, hot dry rock, and magma resources are still in the early stages of technological development.

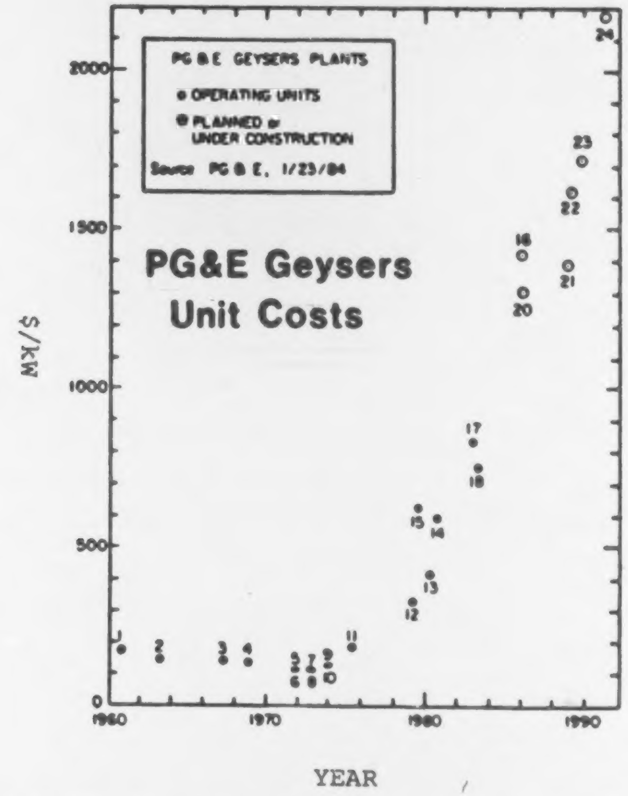
Hydrothermal Resources

There are six basic types of *hydrothermal* electric conversion technologies that are in various stages of development: dry steam generation, single flash, dual flash, binary cycle, total flow cycle, and compound or hybrid plants.

Exploiting *dry steam* resources is a simple and reliable process using equipment developed in the conventional power generation industry. Extensive development using dry steam has occurred in the Geysers in California and in Italy. Dry steam is a rare resource, however. Most resources are a mixture of steam and hot water, unsuitable for powering steam turbines directly. As a result, costs for dry steam geothermal plants at the Geysers have been rising rapidly in recent years, but economically competitive electricity is still being produced in the Geysers.(5) Capital costs are less than $1000/kWe installed, with electricity generated at a cost between 5.5-5.9¢/kWhe (see FIGURE 3-6).(16)(29) However, a standard 114 MWe unit estimated to come on line in 1990 is expected to double in cost to $2176/kWe.(16)

FIGURE 3-6

PAST AND PROJECTED COSTS OF GEYSER GEOTHERMAL PLANTS



Source: Ronald DiPippo, "Worldwide Geothermal Power Development: 1984 Overview and Update," Geothermal Resources Council Bulletin, Vol. 13, No. 9, October 1984, p. 4.

Single flash systems are considered less efficient than other geothermal systems for exploiting liquid-dominated geothermal resources, but are also less expensive to build and easier to maintain. Single flash systems are well developed and are considered economic in many locations at sizes from 10 to 55 MWe.(31) The Department of Energy has estimated that a 50 MWe single flash plant will cost between $95 and $140 million, or $1900-$2800/kWe installed. Annual operations and maintenance (O&M) costs will amount to between $4.75 to $11.2 million a year.(31)

Because *dual flash* systems use both steam and water, instead of just steam, these systems produce about 15% more energy than single flash systems.(15) However, flashing the hot water reduces its temperature and causes some of its solids to precipitate, particularly silica. As a consequence, preventing scaling, corrosion, and erosion within the flashing equipment from the precipitating materials poses one of the largest problems for single and dual flash systems.(15)(23)

There are currently no operating dual flash systems in the U.S., although five are under construction. A 47 MWe system in Southern California is expected to come on-line in 1985. There are approximately 26 operating in other countries, with total generating capacity of approximately 396 MW.(30)(23) By 1995, dual-flash geothermal capital costs for a 50 MWe plant will probably be between $1,300 and $1,600/kWe. If the geothermal brine is highly saline, costs could escalate to $2,000/kWe.(23) Operations and Maintenance (O&M) costs should be in the range of 1-5¢/kWh and brine costs (assuming the field developer sells steam to the powerplant developer) should be in the range of 5-7¢/kWh.(29)

Although *binary cycle* technology has only recently been commercially demonstrated in small (less than 10 MWe units), at least five countries have operating or planned binary plants. The greatest developments have occurred in the U.S. As of June 1984, two systems were operational (10 MWe and three 0.3 MWe units), four installations were under construction (two 3.5 MWe units), five 0.6 MWe units, nine 45 MWe units, three 0.4 MWe units), and one 5 MWe unit was still in the planning stages.(16) Nine projects in other countries will generate approximately 4 MWe total.(30) A 45 MWe (net) commercial demonstration plant at Heber, California, the world's first plant over 10 MW, is scheduled to come on-line in 1985, with hopes the plant will provide the technical and economic data needed to lead the technology to commercial status.(29)(31) In the 1990s, binary plant costs could range from $1,500 to $1,800/kWe for 50 MWe plants, and from $1,500 to $2,000/kWe for smaller, modular, wellhead units (5-10 MWe net). O&M costs are expected to range between 1-5¢/kWh for the large units (50 MWe net), but between 0.4-0.6¢/kWh for the smaller units.(23)

Binary plants have higher parasitic power requirements than flash plants, since they must operate pumps for both the working fluid and the geothermal water. They also use more cooling water than dry steam and flash plants.(15)(29) However, binary plants can use geothermal resources 30-60% more efficiently than flash systems and can be extremely clean running plants.(29)(31) An air-cooled binary cycle power plant went on-line in 1984 near Mammoth Lakes, California. It was built at a cost of $1250/kWe and has performed well, with availabilities exceeding 90%.(19) If the binary cycle technology is successfully developed, low-to-moderate temperature reserves can be opened up for economic exploitation.(30)

Operating availability for both *dual-flash* plants and *binary* plants should be between 90-95%, and the capacity factor should be between 75-85%.(34) Geothermal plants are expected to last at least 30 years. According to the U.S. Department of Energy, current two stage flash or binary conversion technology is cost effective if the brine is at least 340° and 392°F (170° and 200°C), respectively. It becomes increasingly economical at higher temperatures. Wells now being developed at depths of about 1.24 miles (2 kilometers) and providing flow rates of about 200 kg/hr at not less than 400°F (200°C) are producing electricity at about the same cost as electricity from coal.(31)

Several different system configurations are being explored for *total flow cycle* systems, including impulse and reaction hydraulic turbines, a rotary separator turbine, and positive displacement engines.(4) So far, the rotary separator turbine (RST) show the most promise and are being studied for commercial application in the U.S. In a rotary separator turbine system, special nozzles expand and accelerate geothermal steam and water and direct them tangentially against the inner surface of a disk to turn a central shaft attached to a generator. The steam is vented and directed through a steam turbine and a liquid turbine is driven by the fast moving water pulled from the disk. RST technology is just now becoming commercialized, with two RST plants, 9 and 14.3 MWe each, in the planning stages.(29)

Various *compound or hybrid systems* have been proposed to increase overall efficiency. These suggestions include combining flash and binary systems, hybrid fossil-geothermal systems, wood-waste-geothermal systems, and multi-use (cogeneration) systems generating electricity and using the waste heat for space heating or other uses.(15)

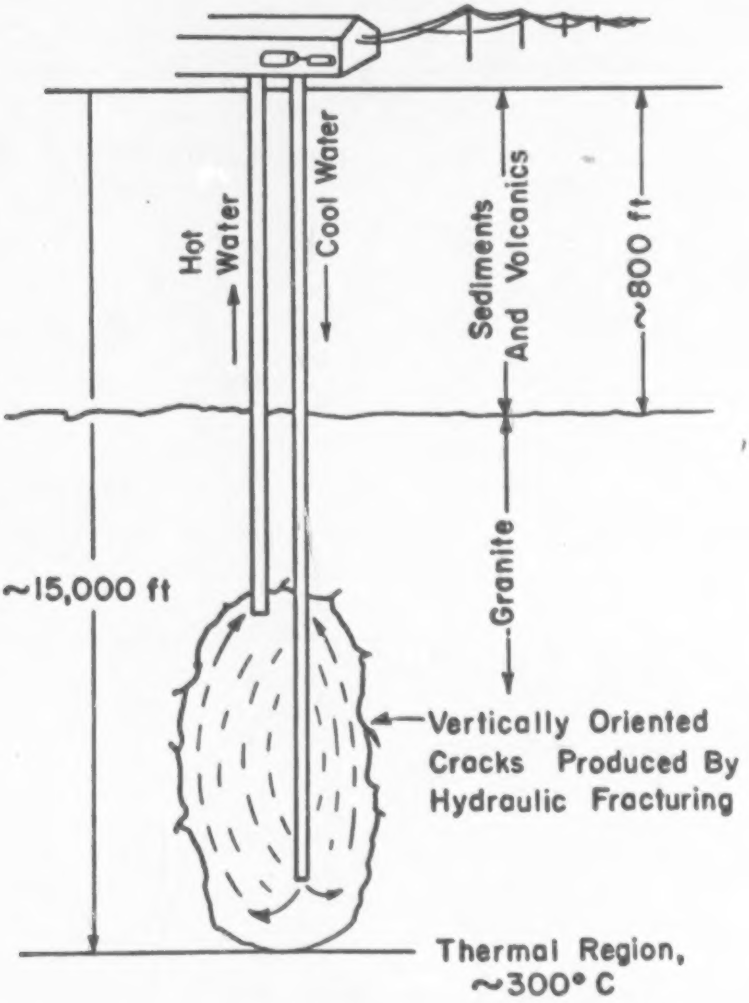
Geopressured Resources

To date, most research on *geopressured resources* has centered around evaluating their potential. Twelve wells have been drilled to test flow rates. Temperatures from these wells seldom exceeded 300°F (150°C), and their heat resource is now considered marginal compared to other geothermal resources.(28) At most wells, rates have been less than anticipated and none have exhibited performance that was economically promising for either methane or electricity production. Advances in conversion efficiency may make the low temperature resources profitable. Tests are planned to use the methane content of the geopressured brine to fire a boiler to raise the heat content of the resource for generating electricity.(28)

Hot Dry Rock

Hot dry rock geothermal resources are usually composed of unfractured rock masses. A system of cracks must be created and water circulated to withdraw their heat. After two or more wells have been drilled, hydraulic pressure, explosives, or chemical treatment are used to fracture the rocks, thereby allowing water to circulate from an injection well to a production well (see FIGURE 3-7).(29) The binary cycle is the primary candidate for use with hot dry rock resources, due to the moderate temperature (less than 350°F) of the circulated fluids. After passing through the heat exchanger, the water will be recirculated through the injection well. A 5 MWth (megawatts thermal) hot dry rock system, the world's first, was built by the U.S. government for research and testing at Fenton Hill, New Mexico.

FIGURE 3-7
HOT DRY ROCK SYSTEM


Hot Water
Cool Water
Sediments And Volcanics
~800 ft
~15,000 ft
Granite
Vertically Oriented Cracks Produced By Hydraulic Fracturing
Thermal Region, ~300° C

Source: Commercial Status of Electrical Generation Technologies. California Energy Commission (P300-85-003), June 1985, p. 142.

Water availability, for plant cooling and to make up for seepage from the field, is one of the major constraints. Also, creating a satisfactory fracture for well connections and the loss of injected water are major technical problems yet to be resolved.(34)

Magma

Magma resources are the most abundant of the various forms of geothermal energy; however, no technology has been developed to exploit their energy. The extreme temperature and the great depth of the resource are problems that must be overcome if magma is to be exploited. New innovative concepts will have to be developed, and advances in materials and drilling will also have to be made before the resource can be exploited. The U.S. Department of Energy is funding preliminary engineering and economic feasibility studies, as well as research to develop equipment and materials capable of withstanding the temperatures of the magma environment (up to 2,012°F, or 1,100°C).(31)

GOVERNMENT SUPPORT

Geothermal research and development is conducted in the Geothermal Technology Division at the U.S. Department of Energy. Fiscal Year 1985 funding is $31.8 million, an increase of 5% over Fiscal Year 1984 (see TABLE 3-2 and FIGURE 3-8).

The U.S. Department of Energy also administers the Geothermal Resource Development Fund to assist and accelerate the development and utilization of geothermal energy through loan guarantees. Eight loan guarantees have been issued for a total of $244.4 million, while two additional loan guarantees totaling $99.8 million have been conditionally approved.(34)

The Public Utilities Regulatory Policy Act (PURPA) requires utilities to buy power from small independent power producers at the utilities' avoided cost rates. Small geothermal power plants (under 80 MW) qualify under PURPA regulations.

GEOTHERMAL

TABLE 3-2

U.S. DEPARTMENT OF ENERGY FUNDING FOR GEOTHERMAL RESEARCH AND DEVELOPMENT, BY PROGRAM

($ millions)

	FY83	FY84	FY85
Hydrothermal Industrialization	33.0	1.9	1.0
Geopressured Resources	8.4	5.0	5.4
Hot Dry Rock	7.5*	7.5	7.5
Hard Rock Penetration	0.0*	2.6	4.6
Hydrothermal Research	7.5*	11.3	9.9
Magma Energy	0.0	0.9	1.4
Technology Transfer	0.0	0.1	1.0
Program Direction	1.2**	1.0	1.0
TOTAL	57.6	30.3	31.8

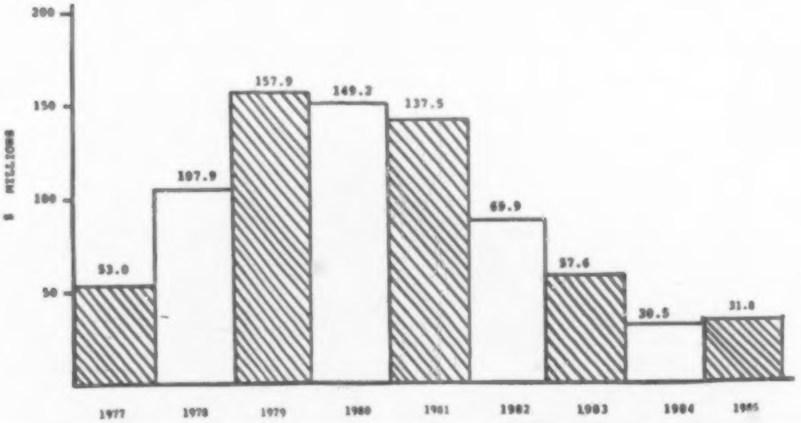
* Provided by Deepak Kenkeremath, Personal Communication (Meridian Corporation, Leesburg, VA), February 4, 1986.

** Provided by Ron Toms, Personal Communication (U.S. Department of Energy, Washington, DC), February 11, 1986.

Source: Department of Energy Fiscal Year 1986 Congressional Budget Request--Energy Supply Research and Development: Solar and Other Renewables, U.S. Department of Energy, Volume 2, pg. 97-98.

FIGURE 3-8

U.S. DEPARTMENT OF ENERGY GEOTHERMAL RESEARCH AND DEVELOPMENT FUNDING, FY 1977 - FY 1985



A 15% federal business energy tax credit for investments in geothermal energy systems, and a 40% residential energy tax credit (limited to $4,000, or 40% of a $10,000 investment) for geothermal systems using resources over 140°F (60°C) expired at the end of 1985. Twenty-one states offer various incentives for the installation of geothermal systems (see APPENDIX I).

INDUSTRY STATUS

Approximately half of the companies working on geothermal energy systems are small companies concentrating exclusively on geothermal technology. The remainder are utilities, oil and gas companies, large engineering firms, and large industrial firms that use geothermal heat and electricity. Most of the geothermal power plants in the U.S. are built by the private sector and are owned by utilities.(30) According to the Geothermal World Directory, 10 drilling companies, 40 engineering firms, 12 exploration firms, 11 instruments firms, 12 firms involved in pollution control, and 38 in support equipment were active in geothermal development in 1984. The directory listed over 1500 entries of companies, consultants, universities, and government agencies involved with geothermal energy in the U.S.(33)

MARKET STATUS

Direct Use

Presently, there are approximately 260 projects in the U.S. directly using geothermal energy that account for an estimated 1,860 billion BTUs annually (see TABLE 3-3).(13) All but one of the present projects are in states west of the Mississippi River, with the greatest concentration in California, Idaho, Oregon, Nevada, and New Mexico.(13)

TABLE 3-3

LEADING APPLICATIONS OF DIRECT USE GEOTHERMAL IN THE U.S

Application	BTUs/Yr. (in billions)	% of Total
Space/Water Heating	473	25
District Heating	426	23
Aquaculture	396	21
Commercial Greenhouses	328	18
Small Resorts	120	7
Industrial Process Heat	118	6
TOTAL	1861	100

Source: Gene V. Beeland, Robert E. Blackett, Deepak C. Kenkeremath, James V. Satrape (Meridian Corporation), "The Current Status of Geothermal Direct Use Development in the United States," 1985 International Symposium on Geothermal Energy, Cona, Hawaii, August 26-30, 1985 (proceedings unpublished).

The biggest user of direct use geothermal in the U.S. are space conditioning and water heating applications. They consume 473 billion BTUs of geothermal heat annually, accounting for 25% of all geothermal direct heat applications. An additional 235 billion BTUs may be used in projects presently under construction.(13) In Klamath Falls, Oregon and Reno, Nevada, 550 and 200 homes, respectively, use geothermal resources for space and water heating, the largest such use in the U.S.(13)

District heating is the next largest application in the U.S., amounting to 426 billion BTUs, or 23% of all direct use geothermal energy production. Eleven geothermal district heating systems exist in the U.S., with six more under construction representing a potential contribution of 198 billion BTUs.(13)

There are eight aquaculture facilities in the U.S. that rely on direct use geothermal. Three systems in the Buhl, Idaho; Wabuska, Nevada and Mecca, California systems account for almost 80% of the geothermal energy consumed for this application.(13)

Commercial greenhouses are another user of direct geothermal resources. There are 28 facilities in the U.S., with the installations at Susanville and Cochella, California; Animas, New Mexico; Salt Lake City, Utah; Twin Falls, Idaho; and Vale Oregon using over three quarters of the 328 billion BTUs that are produced annually.(13)

Two less prominent applications include industrial process heat (IPH) and small resorts or health spas. IPH facilities using geothermal resources are somewhat scattered, in part due to the need for the process heat-consuming facility to be located near a geothermal reservoir if it is to be cost-effective. Only three geothermally-supplied IPH facilities exist in the U.S., with the best known probably being an onion-dehydration plant in Brady Hot Springs, Nevada.(13) The facility is saving its owners an estimated $300,000 annually.(17) Resorts are even more widely distributed, with an estimated 120 using geothermal resources in the U.S. but only accounting for 120 billion BTUs annually.(13)

The future market for direct use of geothermal energy is somewhat uncertain. It is generally considered that these uses are not quite economically feasible without government incentives.(13) The potential market could be very large, especially for the industrial process heat sector. Approximately 35% of current IPH requirements are at temperatures of 160°C or less.(7) Roughly two-thirds of the hydrothermal resources are in the temperature range of 150° to 250°F (66° to 120°C) indicating that a substantial portion of the country's IPH needs could come from geothermal resources if they are extensively developed, and applications are located near identified resource areas.(23)

Electricity Generation

The greatest market growth in geothermal energy in the U.S. has occurred in *electrical generation*, and it is anticipated that sector will continue to be the primary application.(31) By the end of 1984, the U.S. had 1469.11 MWe of capacity installed (see TABLE 3-4), with expectations of 2022 MWe by the end of 1985.(30) The greatest geothermal development by far has occurred in the Geysers dry steam field 90 miles north of San Francisco, California (see TABLE 3-5). By the end of 1984, the Geysers had 1399 MWe of capacity in operation. The Imperial Valley, also in California, has 32.5 MWe of capacity, and all other U.S. installations had a capacity of about 38 MWe (see TABLE 3-5).

TABLE 3-4

PRODUCTION OF ELECTRICITY FROM U.S. GEOTHERMAL SOURCES

Year	Year-End Capacity On-Line (Megawatts)	Production (Million kWh)
1960	12	33
1961	12	94
1962	12	100
1963	27	168
1964	27	204
1965	27	189
1966	27	188
1967	55	316
1968	84	436
1969	84	615
1970	84	525
1971	203	548
1972	322	1,453
1973	441	1,966
1974	441	2,453
1975	559	3,246
1976	559	3,616
1977	559	3,582
1978	559	2,978
1979	742	3,889
1980	1,005	5,073
1981	1,005	5,686
1982	1,129	4,843
1983	1,331	6,075
1984	1,469*	7,715**

* Derived from Ronald DiPippo, "Geothermal Electric Power: The State of the World--1985," Geothermal Resources Council Bulletin, Vol. 14, No. 9, October 1985, pp. 13-14.

** Preliminary.

Source: Annual Energy Review 1984. Energy Information Administration, U.S. Department of Energy (DOE/EIA-0384[84]) April 1985, p. 207.

TABLE 3-5

1984 U.S. GEOTHERMAL CAPACITY BY STATE

(Megawatts)

Location	Operational	Under Construction	Planned
California			
Geysers	1,399.00	393.00	868.2
Imperial Valley	32.50	187.12	194.4
Other	7.00	48.00	50.0
Hawaii	3.00	------	-----
Idaho	5.00	------	-----
Nevada	0.60	34.30	70.5
Oregon	2.01	------	-----
Utah	20.00	19.20	2.3
Total	1469.11	681.62	1185.4

Derived from: Ronald DiPippo, "Geothermal Electric Power: The State of the World--1985," Geothermal Resources Council Bulletin, Vol. 14, No. 9, October 1985, pg. 13-14.

According to the U.S. Geological Survey, the U.S. has the resources and capability to produce between 95,000 to 150,000 MWe for 30 years.(31). The Department of Energy believes that a modest goal for the U.S. market in 1990 is 9,000 to 12,000 MWe.(20)

Worldwide, there were 145 separate power units (turbine-generator sets) in 15 countries with a total capacity of 3,770 MWe in 1984.(16)(30) This is expected to grow to 188 separate power units in 17 countries with a total capacity of 4,764 MWe in 1985 (See TABLE 3-6).

GEOTHERMAL

TABLE 3-6
WORLDWIDE GEOTHERMAL PLANT CAPACITY

Year*	Capacity (MWe)
1979	1758.9
1980	2110.536
1981	2493.086
1982	2558.886
1983	3190.286
1984	3769.686
1985**	4763.981

* Survey taken in June of each year.
** Mid-Year Estimate

Source: Ronald DiPippo, "Geothermal Electric Power: The State of the World--1985," Geothermal Resources Council Bulletin, Vol. 14, No. 9, October 1985, p. 18.

From 1920 to 1978, world capacity grew by 8.3 percent per year, and from 1978 to the present, it grew by 16.5 percent per year.(30)(16) According to DOE, world capacity is expected to increase another 45 percent to 5530 MWe in 1986, and by 1995, it should be over 10,000 MWe.(31) TABLE 3-7 indicates the expected capacity in 17 countries by 1990.

TABLE 3-7

WORLDWIDE GEOTHERMAL POWER CAPACITY 1984-1990

(Megawatts Electric)

Country	1984[a]	1985[b]	1990[c]
United States	1454	2022	2516
Philippines	781	894	1042
Italy	472	519	519
Mexico	425	645	965
Japan	215	215	215
New Zealand	167	167	283
El Salvador	95	95	95
Iceland	41	39	39
Nicaragua	35	35	70
Indonesia	32	32	362
Kenya	30	45	45
U.S.S.R.	11	11	91
China	8	14	14
Portugal (Azores)	3	3	3
Turkey	0.5	21	21
France (Guadeloupe)	0	4	4
Greece	0	2	2
Costa Rica[d]	0	0	50
Saint Lucia[d]	0	0	30
Chile[d]	0	0	15
Guatemala[d]	0	0	15
India[d]	0	0	1
Romania[d]	0	0	1
Australia[d]	0	0	0.5
Total	3769.5	4763	6398.5

[a] Through June 1984.

[b] Projected.

[c] Estimated.

[d] Facilities may come on-line between 1986 and 1990.

Source: Ronald DiPippo, "Geothermal Power Development: 1984 Overview and Update," Geothermal Resources Council, Vol. 13, No. 9, October 1984, p. 3.

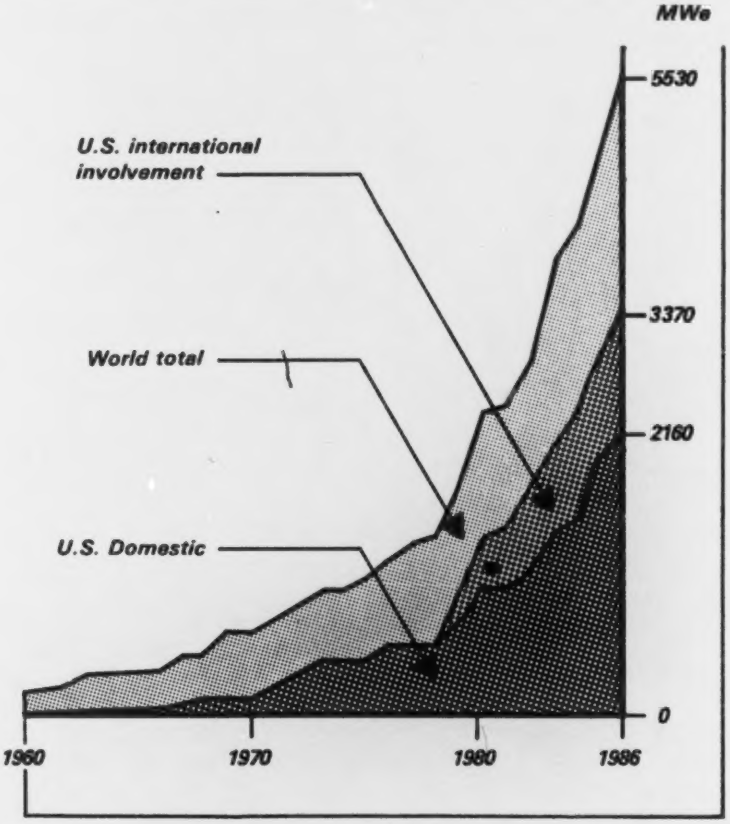
Deepak Kenkeremath (Meridian Corporation) and Dr. John E. Mock (U.S. Department of Energy), "International Geothermal Market Opportunities," 1985 International Symposium on Geothermal Energy, August 26-30, 1985.

International Activity

Worldwide, U.S. companies have assisted on more than half of the installed geothermal capacity (see FIGURE 3-9). U.S. companies primarily export geothermal production field analysis and field development services.(31) Foreign competition will primarily come from countries with geothermal expertise and a developed industry. This includes New Zealand, Japan, Italy, France, and Iceland.(18) Of these, Japan is successfully exporting their hardware into the U.S., particularly their turbo-generator equipment.

FIGURE 3-9

U.S. PARTICIPATION IN GEOTHERMAL ELECTRIC CAPACITY



Source: U.S. Geothermal Technology: Equipment and Services for Worldwide Application. U.S. Department of Energy (DOE/ID-10130), 1985, p. 13.

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Chapter 4

HYDROPOWER

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HYDROPOWER

RESOURCE AVAILABILITY

The movement of water flowing from a higher to a lower elevation has long been recognized for its energy value. The energy potential from available resources in the U.S. and abroad make hydropower one of the most significant energy sources today. At the same time, an abundance of undeveloped resources still exists worldwide.

The United States currently receives 14% of its electricity, or nearly 5% of its total energy supply, from hydroelectric generating stations, with a total capacity of over 66,000 MWe.(11) The majority comes from large-scale facilities located on the nation's largest rivers. More recently, development of smaller, more decentralized resources have been recognized as an important energy contributor for the future. In addition, the creation of man-made hydraulic resources —pumped hydro-- has the potential of expanding the nation's hydroelectric resource availability considerably (see TECHNOLOGY DESCRIPTION).

Estimates of undeveloped hydropower potential in the U.S. range from 26,000-77,000 MWe of generating capacity.(10)(26) The Federal Energy Regulatory Commission's Inventory of Hydropower Resources analysis indicates that the U.S. has developed only 46% of its total conventional hydroelectric power generation potential (see FIGURE 4-1 and TABLE 4-1)(26). Small-scale hydropower resources, generally considered to be sites of less than 30 MWe have been estimated to be between 5300 and 10,500 MWe.

In addition, the energy output of the nation's existing facilities could be increased 11% by capturing the spill, adding 29,980 gigawatt hours (GWh) to the existing 321,000 GWh generated in 1984.(10)(11)

FIGURE 4-1

CONVENTIONAL HYDROELECTRIC POWER IN THE U.S. DEVELOPED, UNDEVELOPED, AND TOTAL POTENTIAL (January 1, 1984)

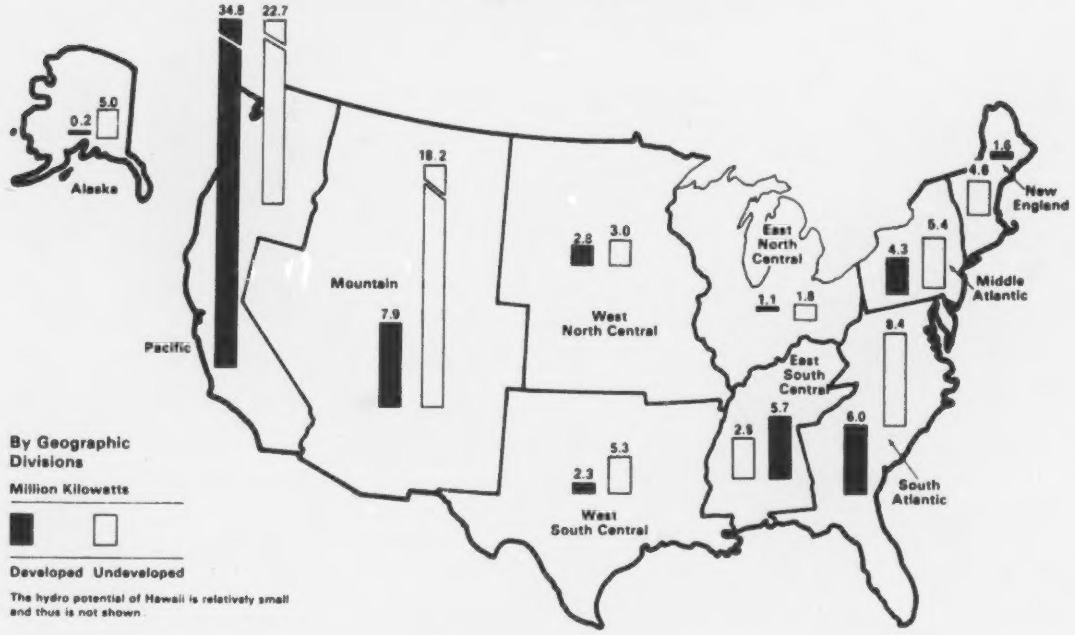

34.8
22.7
Pacific
0.2
5.0
Alaska
18.2
Mountain
7.9
2.8
3.0
West North Central
5.3
2.3
West South Central
East North Central
1.1
1.8
East South Central
2.9
5.7
6.0
8.4
South Atlantic
4.3
5.4
Middle Atlantic
4.6
1.6
New England
By Geographic Divisions
Million Kilowatts
Developed
Undeveloped
The hydro potential of Hawaii is relatively small and thus is not shown

TABLE 4-1

CONVENTIONAL HYDROELECTRIC POWER IN THE U.S. DEVELOPED, UNDEVELOPED, AND TOTAL POTENTIAL (January 1, 1984)

GEOGRAPHIC DIVISION	DEVELOPED			UNDEVELOPED			TOTAL POTENTIAL		PERCENT TOTAL POTENTIAL CAP NOW DEVELOPED
	NO. OF PLANTS	INSTALLED CAPACITY KW	AVERAGE ANNUAL GENERATION 1.000 KWH	NO. OF SITES	INSTALLED CAPACITY KW 1/	AVERAGE ANNUAL GENERATION 1.000 KWH	INSTALLED CAPACITY KW	AVERAGE ANNUAL GENERATION 1.000 KWH	
NEW ENGLAND	279	1.618.736	6.684.866	744	4.555.434	13.887.230	6.174.170	20.571.296	26.2
MIDDLE ATLANTIC	157	4.297.372	25.703.831	421	5.370.969	18.152.584	9.668.341	43.856.415	44.4
EAST NORTH CENTRAL	210	1.087.054	5.159.366	208	1.789.913	7.158.041	2.876.967	12.317.407	37.7
WEST NORTH CENTRAL	65	2.808.465	12.187.539	157	3.011.876	9.999.018	5.820.341	22.186.557	48.2
SOUTH ATLANTIC	166	6.013.182	17.216.643	355	8.395.423	17.795.208	14.408.605	35.011.851	41.7
EAST SOUTH CENTRAL	97	5.734.292	22.024.618	119	2.842.266	9.337.538	8.576.558	31.362.156	66.8
WEST SOUTH CENTRAL	43	2.338.020	6.516.705	214	5.328.495	12.734.953	7.666.515	19.251.658	30.4
MOUNTAIN	192	7.867 611	32.866.583	876	18.201.259	53.698.630	26.070.870	86.565.213	30.1
PACIFIC	337	34.835.480	167.391.690	1472	22.691.726	66.296.271	57.527.206	233.687.961	60.5
ALASKA	26	155.737	634.082	96	5.041.107	22.192.656	5.196.844	22.826.738	2.9
HAWAII	14	17.652	104.102	15	62.890	310.950	80.542	415.050	21.9
TOTAL UNITED STATES	1546	66.775.601	296.489.223	4677	77.291.358	231.563.079	144.066.959	528.052.302	46.3

Sources: Hydroelectric Power Resources of the United States: Developed and Undeveloped. Federal Energy Regulatory Commission (FERC-0070), January 1984, p. x and xi.

Hydroelectric power sources provided a quarter of the world's electricity, or 1,883 billion kilowatt hours (1,883,000 GWh) in 1983.(11) The World Energy Conference, in 1980, estimated the world's technically usable potential to be 19,000,000 GWh, produced at dams with a total generating capacity of 2,214,700 MWe (see TABLE 4-2).(12)

TABLE 4-2

WORLD HYDROPOWER POTENTIAL AND USE, BY REGION, 1980

(megawatts electric)

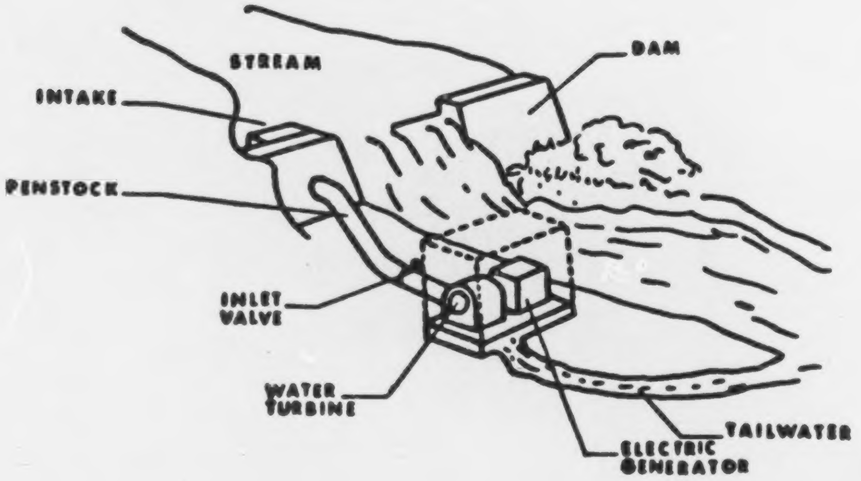
Region	Technically Exploitable Potential	Exploited Resources	Share of Potential Exploited
Asia	610,100	53,079	9%
South America	431,900	34,049	8%
Africa	358,300	17,184	5%
North America	356,400	128,872	36%
USSR	250,000	30,250	12%
Europe	163,000	96,007	59%
Oceania	45,000	6,795	15%
World	2,200,000	363,000	17%

Source: World Energy Conference, Survey of Energy Resources, 1980.

TECHNOLOGY DESCRIPTION

Hydropower is derived by converting the potential energy of water to electrical energy, using a hydraulic turbine connected to a generator. A hydroelectric power project consists of civil, hydraulic, mechanical and electrical works. The principle components of a typical hydropower installation exploiting the natural fall in a stream or river are shown in FIGURE 4-2. Water is diverted from the stream and conveyed through a pipeline under pressure (penstock) to the turbine. Water is released from the turbine, through a draft tube, back to the stream at a downstream location.

FIGURE 4-2
TYPICAL COMPONENTS OF A HYDROELECTRIC POWER PLANT



Source: Site Owner's Manual for Small Scale Hydropower Development. New York State Energy Research and Development Authority (Report 79-3), March 1980, pp. 1-5.

The electrical energy which can be produced by a hydropower system depends on the rate of flow of available water, the head or vertical difference between the water level prior to entering the penstock and the location of discharge after passing through the power generation station (powerhouse), and the efficiency of the process.(3)

Most hydropower installations require construction of a dam to capture and regulate the flow of water. It can also add to the elevation of the water by raising the surface level, thus providing greater head to operate the turbine. The dam may also serve other water resource development purposes.

Hydropower projects can be subdivided by size (large-scale, small-scale, and micro-hydro) and type (pondage, run-of-the-river, pumped storage or conventional):

HYDROPOWER

- *Large-scale hydropower* facilities are among the most impressive civil works achievements in the world. These projects range from 100 to several thousand feet in dam elevation (head), and can include generating capacities of up to 12,000 MWe. Many large-scale hydropower projects incorporate several turbines and sometimes multiple dams.

- *Small-scale hydropower* facilities are generally between 100 kWe and 30 MWe in capacity and less than 100 feet in dam elevation. For the purposes of federal programs, the definition varies, i.e., the Corps of Engineers' definition includes "dams less than 100 feet in height, less than 10,000 acre-feet of reservoir storage capacity, and with a potential generating capacity of less than 5 MWe"; the Department of Energy defines small-scale hydropower projects as being "installed generating capacity of not less than 100 kWe and not more than 30 MWe"; and the U.S. Congress' definition, for regulatory purposes, includes projects "which have not more than 15 MWe of installed capacity" or for purposes of tax treatment includes only those projects having a capacity of 25 MWe or less.

- *Micro-hydro* projects are the smallest possible small-scale installations, some with less than 1 kWe of generating capacity.

- *Pondage hydropower* stations employ dams to restrain waterways in order to create pressure. The reservoir that is established can be used to store water, releasing it when it is most needed to generate electricity.

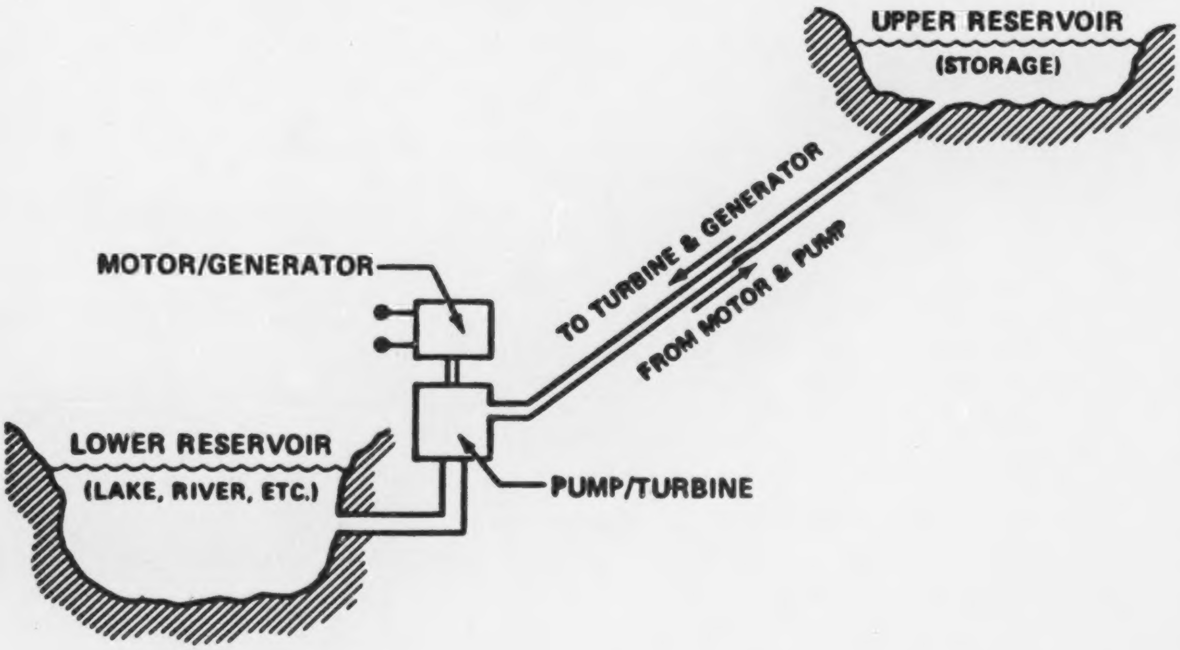
- *Run-of-the-river* systems also employ a dam, but with limited reservoir storage. The amount of pressure, therefore, is determined by the actual flow of the stream or river. This way river flow is not as greatly impacted, but power is generated "as available" instead of during optimal periods of demand.

- *Pumped storage* hydropower systems generate electricity in the same manner as conventional hydropower plants; however, they also have the ability to pump water from a lower to a higher elevation (see FIGURE 4-3). While this "pump-back" operation consumes energy, the value of having the water available for peak demands outweighs the cost of the energy used to recharge the upper reservoir. Pumped storage hydropower stations use natural topographic features or extensive underground waterways to achieve the desired head.

- *Conventional* hydropower stations refer to all facilities that are not pumped-storage.

FIGURE 4-3

PUMPED-HYDROELECTRIC POWER SYSTEM STORAGE


UPPER RESERVOIR
(STORAGE)
TO TURBINE & GENERATOR
FROM MOTOR & PUMP
MOTOR/GENERATOR
LOWER RESERVOIR
(LAKE, RIVER, ETC.)
PUMP/TURBINE

Source: "Hydroelectric Power--1983 was a Record Year," Electric Power Quarterly, October-December 1983, p. 6.

APPLICATIONS

Mechanical energy can be derived by coupling the hydraulic runner (water wheel) directly to applications such as grain and textile milling. While once the prominent use of hydropower, there are few remaining systems of this kind.

The generation of *electricity* has become the primary application of hydropower installations, and most hydropower projects are connected to the electric grid. Pondage hydropower stations with sufficient reservoirs are used both for baseload and peaking purposes. That is, electricity is generated continuously, but the output can be increased to meet periods of greater demand.

Run-of-the-river projects do not have the ability to store the potential energy of the hydraulic resource and, therefore, produce power "as available". However, large-scale, run-of-the-river projects are considered to be baseload since their output is relatively constant.

Pumped-storage facilities have been developed primarily in response to the increasing value of electric energy. Here, electricity generated during periods of low demand can be used to pump water into the storage reservoir. The water then can be released through a turbine at times of peak demand. The generation in excess of the demand is used to pump the hydraulic resource into the upper storage reservoir.

Non-grid-connected hydropower facilities are usually quite small and supply power to remote homes and farms where access to the existing grid is limited.

Some hydraulic projects can serve more than one basic purpose, e.g. water supply, irrigation, navigation, flood control, recreation, or wildlife conservation. Projects originally designed for non-energy applications can be retrofitted with turbines and generators.

TECHNOLOGY STATUS

Hydraulic energy began as a labor saving device for agricultural and other applications. Tens of thousands of water wheels were located throughout Europe in the 1700's. By the end of the 18th century, there were some 10,000 such installations in the U.S., primarily in New England.(1)(23)

In 1820, French engineer Benoit Foureyon invented the hydraulic turbine, a submersible, compact, and more efficient machine for energy exchange. Such a turbine was first linked to a generator to produce electricity in

1882 in Wisconsin. By 1901, George Westinghouse installed a hydropower system at Niagara Falls and converted the system's direct current (DC) output to alternating current (AC) for transmission purposes.(1)

The first hydropower plants in the U.S. and in Europe were small-scale, run-of-the-river types, many of which ceased to generate electricity during the "dry season". Since World War II, almost 3,000 small-scale U.S. dams have been abandoned (primarily in the Northeast and Midwest) as cheap and abundant fossil fuels became available.(1) At that time, focus shifted to large-scale projects. Today, the U.S. receives electrical energy from a variety of sizes of hydropower facilities, ranging from the 6,000 MWe Grand Coulee Dam to 30 kWe or less run-of-the-river plants. The diversity of sizes is apparent in TABLE 4-3.

TABLE 4-3

1984 U.S. UTILITY HYDROPOWER PLANTS, BY SIZE AND FREQUENCY*

Size Range (MW)	Number of Installations
1000+	12
500-1000	26
100-500	112
30-100	186
5-30	335
1-5	332
<1	197
TOTAL	1200

* Does not include non-utility owned facilities.

Source: Energy Information Administration, Inventory of Electric Utility Hydro Plants For Year 1984.

Large-Scale Hydropower

In the 1930's, accompanying the establishment of the Tennessee Valley Authority (TVA), hydropower developments in the U.S. centered on the construction of enormous dams in the middle or lower sections of the nation's largest rivers. Other countries have developed large-scale hydropower resources as well. Some of these projects remain the largest generating stations in the world, many times larger than the size of an average nuclear or fossil-fired power plant. With the exception of the Soviet Union and Canada, large-scale hydropower development has shifted to developing countries (see TABLE 4-4).

TABLE 4-4

LARGEST HYDROELECTRIC PROJECTS
(Operating, Under Construction or Planned)

Plant	Country	Rated Capacity (megawatts)	Year of Completion
Three Gorges*	China	18,000	2000
Itaipu	Brazil/Paraguay	12,600	1990
James River**	Canada	10,269	1985
Guri	Venezuela	10,000	1986
Tucurui	Brazil	8,000	1985
Grand Coulee	United States	6,494	1942
Sayano-Shushensk	Soviet Union	6,400	1984
Corpus Posadas	Argentina/Paraguay	6,000	1988
Krasnoyarsk	Soviet Union	6,000	1973
Churchill Falls	Canada	5,225	1971
Bratsk	Soviet Union	4,500	1964
Ust-Ilim	Soviet Union	4,500	1978
Yacyreta-Apipe	Argentina/Paraguay	4,050	1988
Caora Bassa	Mozambique	4,000	1974

* Personal communication, Christopher Flavin (Worldwatch Institute, Washington, D.C.), February 13, 1986.
** Combined output of La Grande units 2,3,4.

Source: T.W. Mermel, "Major Dams of the World," Water Power & Dam Construction, August 1983.

The large-scale hydropower plants in the U.S. have operated successfully for decades and are responsible for the inexpensive power in certain regions of the country such as the Pacific Northwest. Conventional hydropower plant availability is approximately 95%.(13)(22) However, 63% of the existing licensed hydro plants are now over 50 years old and much of the nation's potential for new large-scale hydropower is restricted, due to land-use and environmental impact concerns.(13) For these reasons, the majority of the developments in large-scale conventional hydropower will come from revitalization and capacity expansion of existing facilities.

A capacity increase can be achieved by an increase in net head, discharge rates, improved efficiencies of the system components, adding or replacing turbines, or any combination of these steps. Increasing the capacity of an existing hydropower plant has been achieved for as little as $40-$60 per incremental kilowatt, but most likely will cost between $200 and $700 per kWe.(14) These costs compare very favorably to the costs of installing a new hydropower plant or any other type of generating station.(13)

Pumped Storage Hydropower

Pumped storage development began in the U.S. in 1929 with the Rocky River project in Connecticut. This pumped storage facility was located near run-of-the-river hydropower project due to suitable topography. This helped save the "lost" generation when output of the run-of-the-river facility exceeded electrical demands. The excess power was used to operate the pumping cycle of the pumped storage plant.(5) These systems have also been used as reliable energy storage systems for non-hydropower plants. Through the use of pumped hydro, capacity factors of base-load coal and nuclear generating plants can be increased.(13) A typical pumped storage hydropower plant has a pumping/generating ratio of 1.5 to 1.(5)

The majority of pumped storage hydropower systems are sited in geographic areas with sufficient differences in elevation in a relatively short horizontal distance, so that a facility's upper and lower reservoir can be in reasonable proximity to one another. With the recent development of underground pumped hydro, reservoirs can be sited 5000 feet (1524 meters) below the surface to provide a nearly limitless potential for the technology.(13) The only current underground pumped storage hydropower plant in the U.S. is the Helms facility in northern California, with 1700 feet (530 meters) of hydraulic head between the upper and lower reservoirs. The future of underground pumped hydro depends on reducing tunneling and excavation costs.

The technology for pumped hydro in the U.S. has evolved from the use of a electrically powered pump to fill the upper reservoir and a separate hydraulic turbine to convert the released water pressure to useful energy. Large-scale pumps, in recent decades, have been mechanically integrated with reversible turbines; yet these systems have not been developed for very high heads.

Today, operating pumped hydropower facilities range from 60 to 1,500 maximum feet (18.2 to 457 meters) of head, and 7 to 1,872 MWe of installed capacity. The world's largest pumped hydro facility (2,100 MWe) is the Bath County plant in Virginia, scheduled to come on-line by the end of 1985.(5) Pumped storage hydropower facilities in the U.S. have a historic record of 85% average availability, as compiled by the North American Electric Reliability Council.(22)

Small-Scale Hydropower

Small-scale hydropower, defined here as under 30 MW, represents a cost-effective option for adding new generating capacity in many parts of the U.S. Accompanying the energy crisis of the 1970's, there was a resurgence in the interest in small-scale hydropower development. Much of the revived interest can be attributed as much to legislative and regulatory actions as to technological developments (see GOVERNMENT SUPPORT).

The elements of a small-scale hydropower project can be divided into two main categories: civil versus electro-mechanical features. The civil features include site preparation, the dam, the spillway, and the hydraulic conveyance facilities. The electro-mechanical features include the powerhouse and associated equipment. Depending on the type and capacity of the hydraulic turbine and electrical generator, and the amount of civil features work that is required, the cost of the powerhouse and associated electro-mechanical equipment can vary from about one-quarter to one-half of the total cost of developing a small-scale hydropower facility.(3) The powerhouse features will usually have a fixed cost relative to the size of the project. However, the cost of the civil features can vary greatly due to site preparation and environmental compliance. For these reasons, savings in development costs may be realized through rehabilitation of sites that previously generated hydroelectric power, or where changes in water flow have been established. Estimates of the cost of developing small-scale hydropower projects range from $1200-$3000/kWe installed. Very small microhydro projects can cost as much as $4000-5000/kWe installed.

Hydraulic Turbines

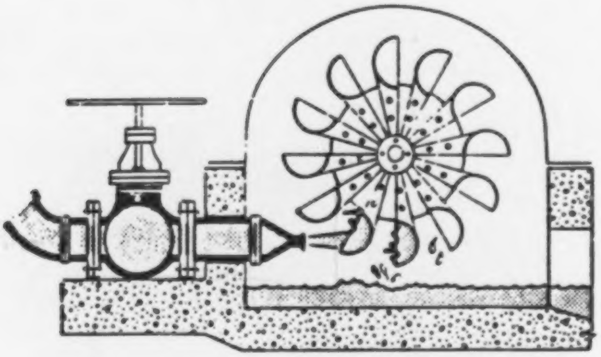
During recent years, hydraulic research and development efforts have concentrated on improving the shape of water passages to reduce hydraulic losses and increase efficiency. Also, emphasis has been placed on widening the stable operating ranges of turbines relative to heads and flow rates.(14)

There are two types of hydraulic turbines, *impulse* and *reaction*. Reaction turbines are by far the most widely used turbines for small-scale hydropower installations.(3) Impulse turbines turbines are used primarily for large-scale, site specific installations. Few manufacturers of impulse turbines are interested in developing a standardized product line, mainly because manufacturing a reaction turbine of comparable head and capacity costs less than that of an impulse turbine.(3)

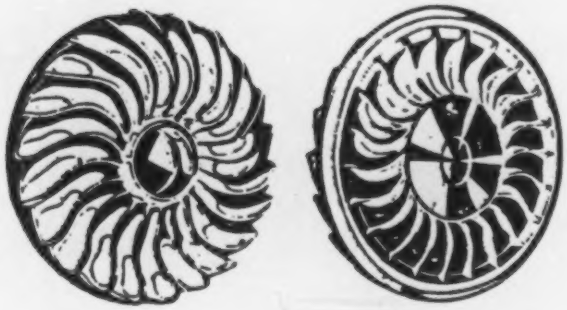
Impulse turbines operate as water is propelled against the periphery of a runner. The main type is the Pelton Wheel, consisting of a wheel or runner with a series of buckets attached around the perimeter (see FIGURE 4-4). Other models include the Turgo and crossflow types. Impulse turbines (Pelton and Turgo types) can operate at heads in excess of 1,000 feet (305 meters) with efficiencies of 85-90%.(4) In older installations using Pelton runners with bolted-on buckets, improved efficiency and structural integrity can be achieved by replacing the original wheels with integral cast runners.(14)

FIGURE 4-4

IMPULSE TURBINES



Pelton Wheel



Turgo Turbine

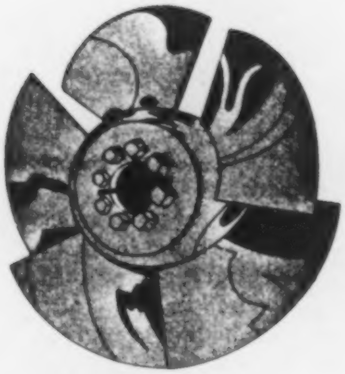
Source: Small Hydroelectric Systems: A Guide to Development in California. California Energy Commission, September 1981, p. 30.

Reaction turbines, which can be used for either large or small-scale hydro, operate by using the pressure and velocity of the water that completely fills the runner and water passages. Reaction turbines can be classified as either Francis or propeller turbines (see FIGURE 4-5). There are several names for propeller turbines including tubular, bulb, Straflo, and Kaplan types.

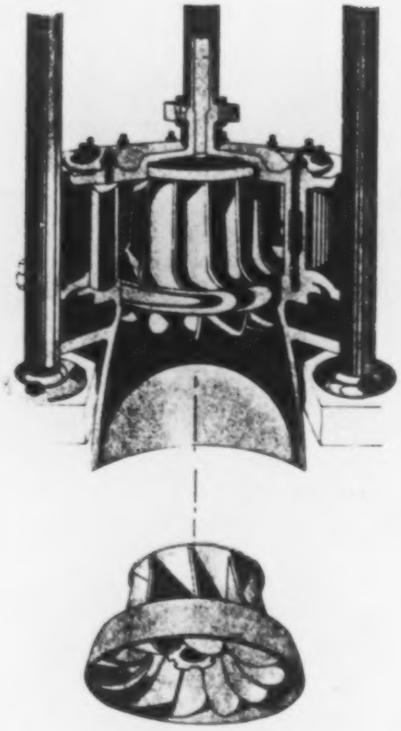
- Francis type turbines are most popular for applications of high unit capacity and when hydraulic heads are in the range of 100 to 2,400 feet (31 to 732 meters). The turbines may be operated over a flow range of 40 to 105% and head range of 60 to 125% of rated design capacity. Efficiencies range from 88-90%, but can drop to 75% when operated at the lower limits of hydraulic head.(4)
- Propeller turbine designs are available for a hydraulic head range of 7 to 268 feet (2 to 82 meters), with more blades being required for upper ranges. They can be operated at flow rates of 40 to 105% and head range of 60 to 140% of rated design capacity. Peak efficiency can drop as much as 15% when operated at minimum heads.(4)(25)

FIGURE 4-5

REACTION TURBINES



PROPELLER TURBINE



Francis Turbine

Source: Small Hydroelectric Systems: A Guide to Development in California. California Energy Commission, September 1981, p. 31 and 33.

TABLE 4-5 lists eleven types of turbines and their characteristics; head, flow rates, efficiency, power output, shaft orientation (vertical, horizontal, or inclined), as well as some general advantages and disadvantages.

TABLE 4-5

Turbine Types & Characteristics

Characteristics Types	Design Head (ft.)	Design Flow (CFS)	Efficiency (%)	Design Power (kW)	Shaft Orientation (V, H, Incl.)	Advantages	Disadvantages
Pelton	40-6,500	1-1,000	90	7-300,000	V, H	High head, small, Good efficiency	Not good for very low head
Francis	12-2,300	3.5-25,000	80-95	7-600,000	V, H	High efficiency	Blade angle adjustment not possible
Propeller	7-260	3.5-23,000	< 94	15-200,000	V, H	Wide flow & head range at good eff. if blades var.	Narrow peak on eff. curve if fixed pitch
Cross-Flow	6-660	1-450	< 83	2.5-2,000	H	Wide flow range	Lower peak eff. than some types
Schneider	3-27	9-2,600	< 75	2-5,200	H	Low head, adaptable to irrigation systems	Reliability yet to be demonstrated
Marine Thruster	3-16	34-1,260	50-75	6.5-1,100	H	Low head, adaptable to irrigation systems	Low efficiency, Unproven reliability
Pump-As-Turbine Axial Flow	8-180	3.5-400	62-89	29-110	H, V	Many designs available off-the-shelf (for small units) Short construction time	Performance prediction difficult from pump performance only. Units available are small. Low efficiency.
Pump-As-Turbine Mixed Flow	12-270	45-1,000	67-88	35-5,000	H, V		
Pump-As-Turbine Radial Flow	17-550	1-210	74-88	10-1,000	H		
Bulb	3-82	7-27,000	84-91	4-60,000	H, Incl.	High efficiency	May require deep excavations
Tube	6-82	45-2,750	74-80	47-15,000	H, V, Incl.	Standardized designs	Low efficiency

Source: John R. Chappell (EG&G Idaho). Hydropower Hardware Descriptions. Small Hydropower Program, U.S. Department of Energy, February 1984, p. 1.

The Peoples Republic of China currently manufacture 84 different types of hydraulic turbines with a capacity up to 10 MW. There are 32 models for capacities of less than 500 kW.(8)(18) The turbines are slightly lower in efficiencies than the U.S. counterpart but are also cheaper per unit capacity.(8)

GOVERNMENT SUPPORT

Federal research and development support for small-scale hydropower comes from the Geothermal and Hydropower Technologies Division of the Office of Conservation and Renewable Energy, U.S. Department of Energy. For Fiscal Year 1985, the Small-Scale Hydropower research and development budget was $437,000, a 41% decrease from Fiscal Year 1984 (see TABLE 4-6 and FIGURE 4-6).

Other federal organizations involved in the support of hydropower include the U.S. Army Corps of Engineers, U.S. Department of Interior Bureau of Reclamation, the Federal Energy Regulatory Commission, as well as the Tennessee Valley Authority and the various regional Power Authorities.

The Public Utility Regulatory Policies Act (PURPA) requires utilities to buy electricity generated by non-utility small power producers at the utilities avoided cost rates. Small-scale hydropower facilities of less than 80 MWe of installed capacity generally qualify under PURPA.

An 11% federal business tax credit has been available for projects of less than 25 MWe or less in capacity and are located at an existing dam or at a site where hydroelectricity has been generated in the past. While the tax credit expired at the end of 1985, projects that have met certain conditions prior to the end of 1985 receive an affirmative commitment that extends the 11% tax credit through 1988. Twenty-seven states offer various incentives to stimulate the development of hydro systems (see APPENDIX I).

TABLE 4-6

U.S. DEPARTMENT OF ENERGY FUNDING FOR SMALL-SCALE HYDROPOWER RESEARCH AND DEVELOPMENT, BY PROGRAM

($ millions)

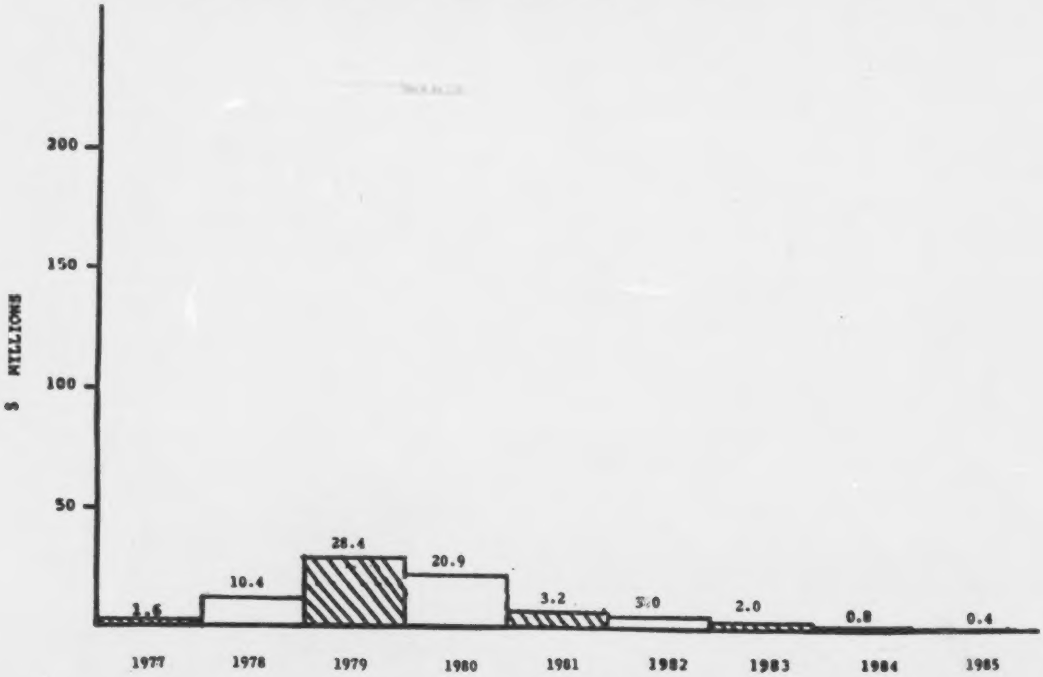
Program Area	FY83	FY84	FY85
Program Planning	0.20	0.25	0.37
Technical Support	1.20	0.50	0.07
Environmental Research	0.60	---	---
TOTAL	2.00	0.75	0.44

Source: Department of Energy Fiscal Year 1986 Congressional Budget Request--Energy Supply Research and Development: Solar and Other Renewables. U.S. Department of Energy, Vol. 2, pp. 117-122.

Renewable Technologies Program Summaries. U.S. Department of Energy, Deputy Assistant Secretary for Renewable Energy, November 1984, pp. 78-84.

FIGURE 4-6

U.S. DEPARTMENT OF ENERGY FUNDING FOR SMALL-SCALE HYDROPOWER RESEARCH AND DEVELOPMENT, FY 1977 - FY 1985



INDUSTRY STATUS

In a survey conducted by Hydro Consultants, Inc., in late 1984, 248 companies identified themselves as providing equipment or services to the North American hydroelectric industry. A large number of equipment companies provide both products and services — development, engineering, project management and/or financial services. However, of the 248 companies listed, 83 are primarily involved with the sale, manufacture, or repair of hydroelectric equipment. Another 165 companies principally supply professional services to the industry.(17) Only one, wholly owned U.S. company manufactures turbines under 30 MWe capacity.

Existing hydropower projects are the result of efforts from a variety of sources, both public and private sector. TABLE 4-7 presents the diversity of organizations involved with the development of hydroelectric energy.

TABLE 4-7

ORGANIZATIONS INVOLVED WITH HYDROPOWER DEVELOPMENT IN THE U.S.

Organization	No. of plants	Total Capacity (MWe)	Percent
U.S. Army Corps of Engineers	70	19,500	25%
Bureau of Reclamation	50	12,500	16%
Tennessee Valley Authority	30	4,800	6%
Federal Power Administrations	10	120	<1%
Nonfederal public agencies*	300	16,000	20%
Rural cooperatives	20	80	<1%
Private utilities	650	24,500	31%
Private non-utilities	350	1,500	2%
TOTAL	1,480	79,000	100%

* State and municipal utilities, irrigation districts.

Source: "More Power From Hydro," EPRI Journal, Vol. 9, No. 2, March 1984, p. 12.

In 1984, 486 MWe of hydropower capacity came on-line.(19) Using an average installed cost of $1500 per kilowatt, this represents an investment of $729 million.

MARKET STATUS

The market for hydropower in the U.S. has shifted from large-scale to small-scale projects, and from government and utility owned to non-utility, independently owned systems. Nonetheless, hydroelectric power is and will remain a vital part of the total U.S. electricity supply mix. Over the past decade, the share of electricity coming from hydropower has varied, due primarily to the level of rainfall and the competing cost of electricity derived from non-hydro sources; i.e., fossil fuels and nuclear power (see TABLE 4-8). TABLE 4-9 indicates the frequency and total installed capacity of hydropower projects since 1980.

TABLE 4-8

HYDROPOWER CONTRIBUTION TO U.S. ELECTRICITY GENERATION

(billion kilowatt hours)

Year	Hydropower	Total Generation	Percent
1973	272	1861	14.6%
1974	301	1867	16.1%
1975	300	1918	15.6%
1976	284	2038	13.9%
1977	220	2124	10.3%
1978	280	2206	12.7%
1979	280	2247	12.5%
1980	276	2286	12.1%
1981	261	2295	11.4%
1982	309	2241	13.8%
1983	332	2310	14.4%
1984	321	2413	13.3%

Source: Annual Energy Review 1984. Energy Information Administration, U.S. Department of Energy (DOE/EIA-0384[84]), April 1985, p. 173.

TABLE 4-9

NUMBER AND CAPACITY OF SMALL-SCALE HYDRO PROJECTS ON-LINE SINCE 1980

Year	Number	Capacity (MW)
1980	7	250
1981	22	188
1982	31	270
1983	70	512
1984	81	486
Total	211	1706

Source: Leslie Eden, "Small Scale Hydro: What's Really Out There," Hydro Review, Waterpower '85, p. 11.

Worldwide, the growth of hydropower over the past decade has been significant (see TABLE 4-10). From 1973 to 1983, electricity from hydropower stations increased 45%.(11) The World Energy Congress estimated that by the year 2020, hydropower will supply 7,920 billion kilowatt hours annually, approximately six times the 1980 level.(1) Over 35 countries (developing and industrialized) receive two thirds or more of their electricity from hydropower.(1)

TABLE 4-10

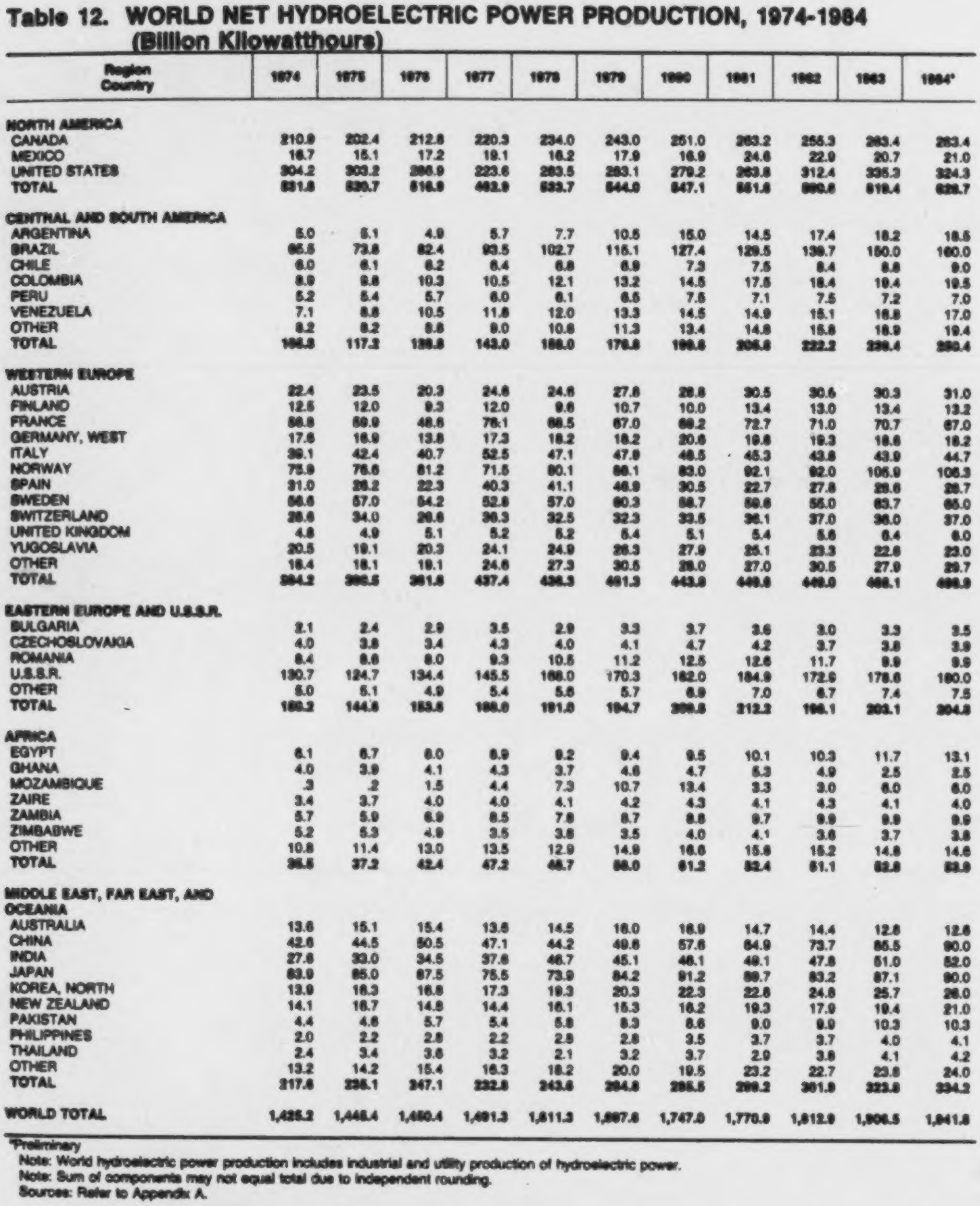


Table 12. WORLD NET HYDROELECTRIC POWER PRODUCTION, 1974-1984 (Billion Kilowatthours)

Region Country	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984*
NORTH AMERICA											
CANADA	210.9	202.4	212.8	220.3	234.0	243.0	251.0	263.2	255.3	263.4	283.4
MEXICO	16.7	15.1	17.2	19.1	16.2	17.9	16.9	24.6	22.9	20.7	21.0
UNITED STATES	304.2	303.2	286.9	223.6	283.5	283.1	279.2	263.8	312.4	335.3	324.3
TOTAL	531.8	520.7	516.9	462.9	533.7	544.0	547.1	551.6	590.6	619.4	628.7
CENTRAL AND SOUTH AMERICA											
ARGENTINA	5.0	5.1	4.9	5.7	7.7	10.5	15.0	14.5	17.4	18.2	18.5
BRAZIL	65.5	73.8	82.4	93.5	102.7	115.1	127.4	129.5	139.7	150.0	160.0
CHILE	6.0	6.1	6.2	6.4	6.8	6.9	7.3	7.5	8.4	8.8	9.0
COLOMBIA	8.9	9.8	10.3	10.5	12.1	13.2	14.5	17.5	18.4	19.4	19.5
PERU	5.2	5.4	5.7	6.0	6.1	6.5	7.5	7.1	7.5	7.2	7.0
VENEZUELA	7.1	8.8	10.5	11.8	12.0	13.3	14.5	14.9	15.1	16.8	17.0
OTHER	8.2	8.2	8.8	9.0	10.6	11.3	13.4	14.8	15.8	18.9	19.4
TOTAL	105.9	117.2	128.8	143.0	158.0	176.8	199.6	205.6	222.2	239.4	250.4
WESTERN EUROPE											
AUSTRIA	22.4	23.5	20.3	24.6	24.6	27.8	28.8	30.5	30.6	30.3	31.0
FINLAND	12.5	12.0	9.3	12.0	9.6	10.7	10.0	13.4	13.0	13.4	13.2
FRANCE	56.8	59.9	48.6	76.1	68.5	67.0	69.2	72.7	71.0	70.7	67.0
GERMANY, WEST	17.6	16.9	13.8	17.3	18.2	18.2	20.6	19.8	19.3	18.6	18.2
ITALY	39.1	42.4	40.7	52.5	47.1	47.8	48.5	45.3	43.8	43.9	44.7
NORWAY	75.9	76.6	81.2	71.5	80.1	86.1	83.0	92.1	92.0	105.9	106.3
SPAIN	31.0	28.2	22.3	40.3	41.1	48.9	30.5	22.7	27.8	28.6	28.7
SWEDEN	56.6	57.0	54.2	52.8	57.0	60.3	58.7	59.6	56.0	63.7	65.0
SWITZERLAND	28.6	34.0	26.6	36.3	32.5	32.3	33.5	36.1	37.0	36.0	37.0
UNITED KINGDOM	4.8	4.9	5.1	5.2	5.2	5.4	5.1	5.4	5.6	6.4	6.0
YUGOSLAVIA	20.5	19.1	20.3	24.1	24.9	26.3	27.9	25.1	23.3	22.6	23.0
OTHER	18.4	18.1	19.1	24.6	27.3	30.5	28.0	27.0	30.5	27.0	29.7
TOTAL	384.2	392.5	361.5	437.4	436.3	461.3	443.8	449.6	449.0	468.1	469.8
EASTERN EUROPE AND U.S.S.R.											
BULGARIA	2.1	2.4	2.9	3.5	2.9	3.3	3.7	3.6	3.0	3.3	3.5
CZECHOSLOVAKIA	4.0	3.8	3.4	4.3	4.0	4.1	4.7	4.2	3.7	3.8	3.9
ROMANIA	8.4	8.6	8.0	9.3	10.5	11.2	12.5	12.6	11.7	9.9	9.9
U.S.S.R.	130.7	124.7	134.4	145.5	168.0	170.3	182.0	184.9	172.9	178.6	180.0
OTHER	5.0	5.1	4.9	5.4	5.6	5.7	6.9	7.0	6.7	7.4	7.5
TOTAL	150.2	144.6	153.6	168.0	191.0	194.7	209.8	212.2	198.1	203.1	204.8
AFRICA											
EGYPT	6.1	6.7	8.0	8.9	9.2	9.4	9.5	10.1	10.3	11.7	13.1
GHANA	4.0	3.9	4.1	4.3	3.7	4.6	4.7	5.3	4.9	2.5	2.5
MOZAMBIQUE	.3	.2	1.5	4.4	7.3	10.7	13.4	3.3	3.0	6.0	6.0
ZAIRE	3.4	3.7	4.0	4.0	4.1	4.2	4.3	4.1	4.3	4.1	4.0
ZAMBIA	5.7	5.9	6.9	8.5	7.8	8.7	8.8	9.7	9.9	9.9	9.9
ZIMBABWE	5.2	5.3	4.9	3.5	3.8	3.5	4.0	4.1	3.6	3.7	3.8
OTHER	10.8	11.4	13.0	13.5	12.9	14.9	16.6	15.8	15.2	14.8	14.6
TOTAL	35.5	37.2	42.4	47.2	48.7	56.0	61.2	52.4	51.1	52.8	53.9
MIDDLE EAST, FAR EAST, AND OCEANIA											
AUSTRALIA	13.6	15.1	15.4	13.6	14.5	16.0	16.9	14.7	14.4	12.8	12.8
CHINA	42.6	44.5	50.5	47.1	44.2	49.6	57.6	64.9	73.7	86.5	90.0
INDIA	27.6	33.0	34.5	37.6	46.7	45.1	46.1	49.1	47.8	51.0	52.0
JAPAN	83.9	85.0	87.5	75.5	73.9	84.2	91.2	89.7	83.2	87.1	90.0
KOREA, NORTH	13.9	16.3	16.8	17.3	19.3	20.3	22.3	22.8	24.8	25.7	26.0
NEW ZEALAND	14.1	16.7	14.8	14.4	16.1	15.3	16.2	19.3	17.9	19.4	21.0
PAKISTAN	4.4	4.6	5.7	5.4	5.8	8.3	8.6	9.0	9.9	10.3	10.3
PHILIPPINES	2.0	2.2	2.8	2.2	2.5	2.6	3.5	3.7	3.7	4.0	4.1
THAILAND	2.4	3.4	3.6	3.2	2.1	3.2	3.7	2.9	3.8	4.1	4.2
OTHER	13.2	14.2	15.4	16.3	18.2	20.0	19.5	23.2	22.7	23.8	24.0
TOTAL	217.6	235.1	247.1	232.6	243.6	264.6	285.5	299.2	301.9	323.8	334.2
WORLD TOTAL	1,425.2	1,446.4	1,450.4	1,491.3	1,611.3	1,697.6	1,747.0	1,770.8	1,812.9	1,906.5	1,941.8

*Preliminary

Note: World hydroelectric power production includes industrial and utility production of hydroelectric power.

Note: Sum of components may not equal total due to independent rounding.

Sources: Refer to Appendix A.

Source: International Energy Annual 1984. Energy Information Administration, U.S. Department of Energy (DOE/EIA-0219[84]), October 1985, p. 22.

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Large-Scale Hydropower

The development of large-scale hydropower has moved from industrialized to developing countries (see TABLE 4-4). Despite the abundance of large-scale hydropower resources left in the U.S., there is little likelihood of further developments in this area, primarily due to concerns over land-use and environmental impact. Instead, the majority of efforts in large-scale hydropower will be retrofitting or revitalizing existing projects or consulting to foreign governments still interested in developing large-scale facilities. On the other hand, Canada's aggressive development plan for hydropower in the Provinces of Quebec and British Columbia is likely to play an increasing role in electricity supply to the northeastern and western United States. In 1984, Canadian hydroelectric power exports to the U.S. were worth $1.5 billion.(2)

Pumped Storage Hydropower

As of 1984, about 3% of total U.S. electricity generation capacity comes from pumped hydro — 16,000 MWe.(13) The percentage of U.S. pumped hydro capacity is quite low compared to Japan (10%); Italy (14%); or France, Germany, and Great Britain (6-7%).(13) Yet, pumped hydro in the U.S. has grown significantly from 0.3% (300 MW) of total hydropower capacity in 1960, to nearly 24% today. Moreover, the construction of 10,000-15,000 MWe of new pumped hydropower facilities is likely to begin in this century.(13) The current pumped hydro development is distributed among 19 states (see TABLE 4-11).

TABLE 4-11

PUMPED STORAGE CAPACITY, BY STATE

State	No. of Plants	Total Capacity (megawatts)
California	7	3,596
Virginia*	2	2,636
Michigan	1	1,872
Massachusetts	2	1,600
Tennessee	1	1,530
New York	2	1,240
Pennsylvania	2	1,222
South Carolina	2	1,121
Georgia	2	824
Colorado	3	645
Missouri	3	626
New Jersey	1	387
Washington	1	314
Oklahoma	1	260
Arizona	2	188
North Carolina	1	117
Arkansas	1	68
Texas	1	34
Connecticut	1	31
TOTAL	36	18,311

* Includes 2,100 MWe plant to come on-line in 1985.

Source: Carl Vansant, "High Tech Hydro: An Overview of Pumped Storage," Hydro Review, Summer 1985.

Small-Scale Hydropower

Small-scale applications represent an important market for hydropower. According to the Federal Energy Regulatory Commission (FERC), there are approximately 1410 small scale hydropower sites on-line or under construction, with a combined capacity of 7019 MWe.(26) One estimate of existing undeveloped small-scale hydropower potential identified 8700 MWe, of which 20-25% is economically viable at this time.(20)

Following government tax and regulatory incentives established in the late 1970's, there has been a surge of non-utility applications to the FERC to develop small-scale hydropower projects. The small-scale hydropower applications have come from throughout the U.S., but the highest concentration comes from the Northeast and West (see TABLE 4-12).

TABLE 4-12

TOP TEN STATES FOR SMALL-SCALE HYDRO DEVELOPMENT IN 1984

(No. of projects [MWe])

State	Projects On-Line	FERC Approved	License/Permit Applications
California	60 (631)	246 (426)	121 (838)
New York	25 (69)	85 (240)	57 (280)
New Hampshire	18 (27)	65 (61)	24 (40)
Idaho	14 (36)	80 (78)	44 (70)
Maine	11 (36)	39 (78)	10 (36)
Washington	10 (206)	68 (243)	95 (459)
Oregon	8 (66)	27 (66)	36 (144)
Colorado	7 (7)	16 (34)	24 (37)
Vermont	7 (5)	40 (88)	16 (57)
Alaska	6 (76)	6 (40)	5 (20)

Source: Leslie Eden, "Small-Scale Hydro: What's Really Out There," Hydro Review. Waterpower '85, p. 14.

For many applications, the greatest influences for bringing a small-scale hydro project on-line are the permitting and licensing process. Federal and state environmental, recreational, safety, archaeological and other requirements can add from eight months to several years to the completion time of a project. At the same time, compliance with these regulations will make many of the proposed projects expensive and difficult to finance. Because of concern over altering water use and stream flow, the greatest potential for small-scale hydropower projects are: 1) run-of-the-river projects that take advantage of existing head and flow release patterns at a site; and 2) use of existing dams where much of the environmental impact has been established and resolved.

In Eastern states, such as New York, New Hampshire, Maine, and Vermont, many projects will be sited at existing dams or impoundments. This will result in less environmental impact and consequently less public opposition. In addition, high avoided cost rates (under PURPA) for these states, will make financing these projects easier.

For Western states, such as Washington, Oregon, California, Colorado, Idaho, and Alaska, many of the projects are sited on "virgin rivers" known for their scenic and recreational value. Here, the cumulative impact of several projects on a river basin is being assessed to determine the environmental impact associated with reduced flow rates. Avoided cost rates in these states vary, but the Northwestern states receive the bulk of their electricity from inexpensive large-scale hydro stations. In these cases, the resulting lower avoided cost rates can lower the revenues for a small hydro project, making them less economically attractive.

Small-scale hydropower is used in many other countries, namely China and France. The Chinese market for small-scale hydropower has been established. By 1982, an estimated 80,000 small-scale hydro projects were implemented with a combined capacity of 8,800 MWe and an annual energy production of 16.3 billion kWh, meeting 20% of their rural energy needs.(27) This represents about one-tenth of the 70,000 MWe of small hydro potential in China considered technically feasible.(21) The government of the People's Republic of China expects to increase current small-scale hydropower capacity three fold by the end of the century, bringing the total to 20,000-25,000 MWe.(27) France receives 1% of its electricity from microhydro stations. In 1980, 1060 projects totaled 390 MW.(1)

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Chapter 5

OCEAN ENERGY

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OCEAN ENERGY

RESOURCE AVAILABILITY

The ocean contains vast energy potential in its waves, in its tides, and in the temperature difference between cold, deep waters and warm surface waters. Caused by winds blowing across miles of open ocean, waves offer a power source for which numerous systems have been conceived. Tides are a result of the gravity of the sun, the moon and the rotation of the earth working together. In some areas of the world, the ocean rises and falls over 40 feet (12 meters) twice a day. The ocean also acts as a gigantic solar collector, capturing the energy of the sun in its surface waters as heat. The temperature difference between warm surface waters and cold water from the ocean's depths provides another potential source of energy.

Ocean Thermal Energy

A temperature differential of at least 38°F (21°C) between surface and deep ocean waters is required to extract energy efficiently from ocean thermal temperature gradients, a condition found only in latitudes within 25° of the equator (see FIGURE 5-1).(1) In the U.S., the Gulf of Mexico, the waters surrounding Hawaii, the Caribbean territories such as Puerto Rico and the U.S. Virgin Islands, and territories like Guam and the Commonwealth of the Northern Mariana Islands all have excellent possibilities for in utilizing the ocean's thermal resources.(10) The Gulf of Mexico alone could potentially supply between 200 to 600 gigawatts (GWe), displacing 15-40 quadrillion BTUs (quads) of energy annually.(18) This is equivalent to 1/4-to-1/2 of the total energy consumed in the U.S. in 1984.(39)

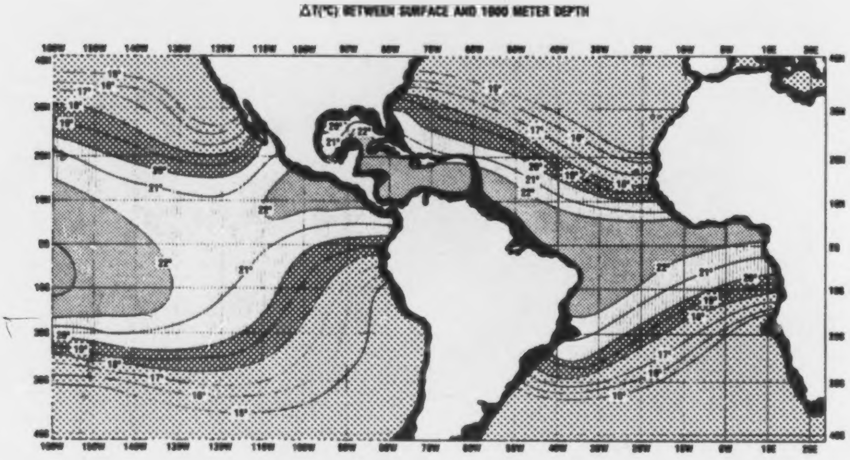
Worldwide, over 20 million square miles of ocean area exist for possible ocean thermal energy conversion (OTEC) sites, yielding as much as 200 to 300 quads per year of energy. The total resource base, according to the

National Oceanic and Atmospheric Administration (NOAA), ranges from 100 million to 10 billion megawatts electric (MWe).(10)

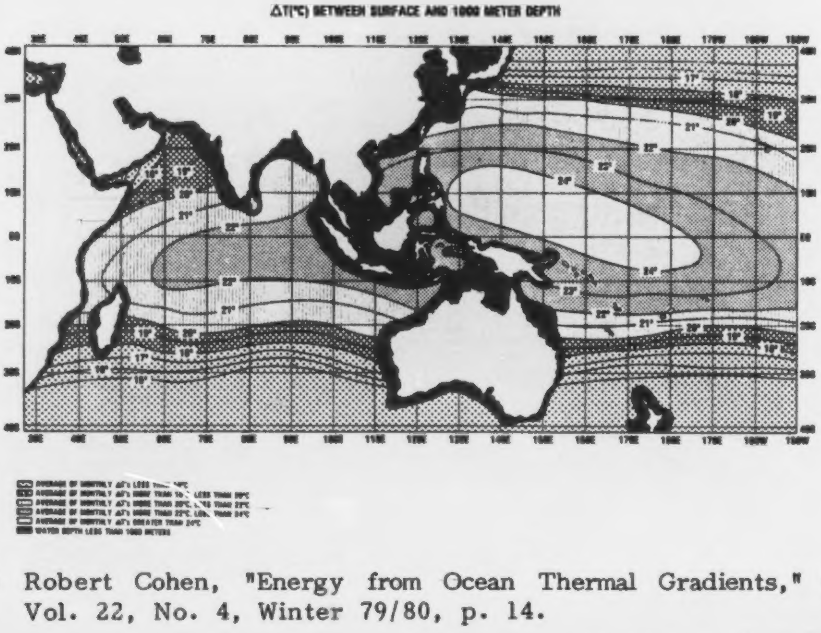
FIGURE 5-1

AVERAGE MONTHLY TEMPERATURE DIFFERENCES
BETWEEN THE OCEAN SURFACE AND DEPTHS OF 1,000 METERS

Western Hemisphere


ΔT(°C) BETWEEN SURFACE AND 1000 METER DEPTH

Eastern Hemisphere


ΔT(°C) BETWEEN SURFACE AND 1000 METER DEPTH
AVERAGE OF MONTHLY ΔT's LESS THAN 18°C
AVERAGE OF MONTHLY ΔT's MORE THAN 18°C, LESS THAN 20°C
AVERAGE OF MONTHLY ΔT's MORE THAN 20°C, LESS THAN 22°C
AVERAGE OF MONTHLY ΔT's MORE THAN 22°C, LESS THAN 24°C
AVERAGE OF MONTHLY ΔT's GREATER THAN 24°C
WATER DEPTH LESS THAN 1000 METERS

Source: Robert Cohen, "Energy from Ocean Thermal Gradients," Oceanus, Vol. 22, No. 4, Winter 79/80, p. 14.

OCEAN ENERGY

Waves

Westerly winds prevail over the earth, causing western coastlines to receive the stiffest waves. Thus, Scotland, Norway, and the west coast of the U.S. have received the most attention for wave energy production.(22) The waves with the greatest amount of force hit Washington and Oregon, with their strength diminishing further south. On the coast of Oregon and Washington, waves have an energy of between eight MWe per mile (five MWe/km) in August to almost 80 MWe per mile (50 MWe per km) in December.(16) California receives waves with a power of 13.2-33 kWe/ft (4 to 10 kWe/m), with higher values in the winter.(1)

Generally, an average of 33-330 kWe/ft (10-100 kWe/m) of beach is delivered by waves in the mid-latitudes, with a possible peak of 1 megawatt per meter (MWe/m) under severe storm conditions. Overall, the amount of power that could be harvested from waves breaking against the world's coastline is estimated to between 10^{12} and 10^{13} watts, or the equivalent of the global consumption of energy.(12)

Tides

The energy from tides is derived from the kinetic energy of water moving from a higher to a lower elevation. Although some designs are being developed that can operate in a tide of only 6.5 feet (2 meters), current designs require a mean tidal range of more than 16.4 feet (5 meters) before power can be produced.(36)

In the U.S., only two sites have been identified for potential tidal power production: Passamaquoddy and Cobscook Bays in the Bay of Fundy in Maine, and Cook inlet in Alaska. These locations have tides of 18.2 feet and 25 feet (5.5 and 7.5 meters), respectively.(1) These areas have a potential energy output of 18,300 GWhe.(36)

Worldwide, tidal power projects could potentially produce 635,000 GWhe, or the equivalent of more than a billion barrels of oil a year.(36) The areas that have the most potential are the upper Bay of Fundy in Canada;

Chausey in the Bay of Mont St. Michel in France; the Gulf of Mezen in the Soviet Union; the Severn River Estuary in England; the Walcott Inlet in Australia; San Jose, Argentina; and Asan Bay in South Korea.(36) The Bay of Fundy alone could produce upwards of 10,000 MWe of electric power.(23)

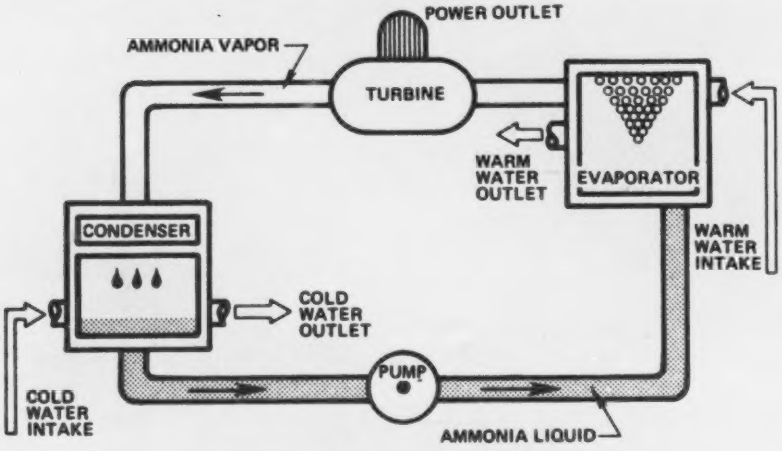
TECHNOLOGY DESCRIPTION

The ocean contains vast stores of energy in many different forms and man is just now learning how to tap some of that energy. The multitude of technologies to convert that energy into useful forms show both the promise and limitations of ocean energy systems.

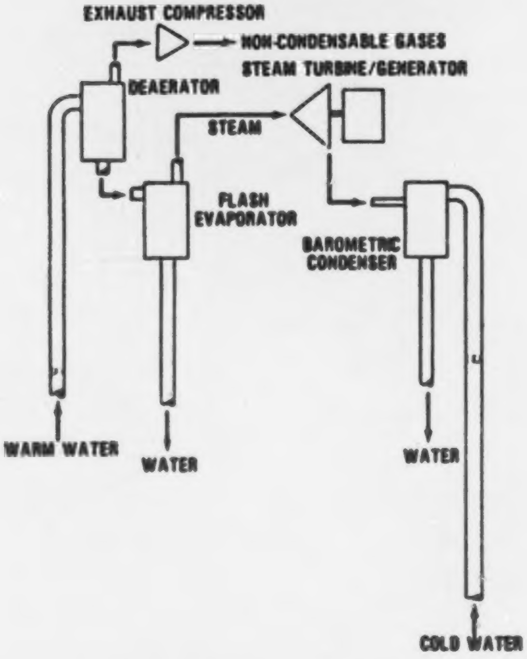
Power from the temperature difference between cold deep water and warm surface water can be generated with either an open-cycle or a closed-cycle *ocean thermal energy conversion* (OTEC) system. In closed-cycle systems, the heat of warm surface sea water vaporizes a working fluid, such as ammonia, which powers a turbine to generate electricity (see FIGURE 5-2). In open-cycle systems, the warm sea water itself is the working fluid; it is vaporized in a vacuum to drive a (steam) turbine to generate electricity (see FIGURE 5-2). In both cycles, cold water that is pumped from the ocean depths condenses the working fluid leaving the turbine. After condensing, the working fluid is pumped back to the vaporizer (closed-cycle), or is pressurized to atmospheric pressure for discharge (open-cycle).

FIGURE 5-2

CLOSED CYCLE AND OPEN-CYCLE OTEC SYSTEMS


POWER OUTLET
AMMONIA VAPOR
TURBINE
WARM WATER OUTLET
EVAPORATOR
WARM WATER INTAKE
CONDENSER
COLD WATER OUTLET
COLD WATER INTAKE
PUMP
AMMONIA LIQUID

Closed-Cycle OTEC System*


EXHAUST COMPRESSOR
NON-CONDENSABLE GASES
STEAM TURBINE/GENERATOR
DEAERATOR
STEAM
FLASH EVAPORATOR
BAROMETRIC CONDENSER
WARM WATER
WATER
WATER
COLD WATER

Open-Cycle OTEC System**

Sources: * Robert Cohen, "Energy from Ocean Thermal Gradients," Oceanus, Vol. 22, No. 4, Winter 1979/80, p. 15.

** V. Daniel Hunt. Solar Energy Dictionary. New York: Industrial Press, 1982, p. 73.

OCEAN ENERGY

Wave power converts the motion of waves into electrical or mechanical energy. Over thirty different systems have been designed to capture wave energy. Most of these systems can be placed into one of three categories: surface followers, pressure activated devices, and focusing devices.(16)

- *Surface followers* use a mechanical connection between a device that floats on the surface of a wave and a fixed pivot to convert the up and down motion of the wave into electricity.
- *Pressure activated devices* use the strength of the incoming wave to force air through an air turbine to generate electricity. Various mechanisms from columns of air to subsurface balloons are used to convert the wave motion into air movement.
- *Focusing devices* use physical barriers to alter the direction and structure of waves to focus their energy to a point. These devices usually use hydroelectric turbines at the focal point of the altered wave, or they take advantage of the enhanced momentum of the wave as it hits the shore. The sea water is collected by a catch basin and returned to the sea through a turbine.

Tidal power extracts energy from tides using the same principles as hydropower facilities but capturing tidal ebbs and flows rather than the flow of a river to generate electricity. The simplest systems generate power by damming a cove in an area with high tides. Sluice gates allow rising tides into the cove and block their exit after high tide. The captured water is released through a turbine to generate electricity. More complicated systems impede the flow of water in both directions and generate power on the incoming and outgoing tides.

APPLICATIONS

Ocean-powered *electrical systems* can come in a wide range of sizes and generating capacity and perform several functions, depending on the concentration of the resource's energy potential.

- Large systems have been proposed as *baseload/utility-size systems* (1 MWe or more) that can generate and supply electrical power continuously to an electricity grid. Since ocean temperatures do not change significantly from hour to hour or even month to month, OTEC systems will generate steady levels of power day in and day out, making them particularly suited for baseload generation. And since tides are also reliable and predictable, tidal power plants can provide baseload generating capacity. (However, since the lunar day is 23 hours long, their peak generating time will change from day to day.) Wave systems have also been proposed for baseload generation, but their production will vary substantially and are therefore not suited for a substantial portion of a grid's generating capacity.

- Ocean energy systems (including OTEC, wave and tidal power) have been offered as ideal *remote power systems* (1 watt - 100 kilowatts) for small communities, remote islands, and isolated shoreline areas that are not tied into a large electricity grid. Wave energy devices have been proposed as power sources for a variety of ocean navigational aids, particularly buoys and lighthouses. A small wave energy generator on a buoy could provide enough power to light its navigation beacon.(12)

- *Industrial process energy* can be derived from ocean energy systems for the production of energy intensive products, chemicals, metals, and other materials. In floating plant ships, energy from the ocean would be used to produce products that require large amounts of electricity. These applications would eliminate the expensive need for transporting electricity from ocean energy facilities to shore. Floating OTEC plant ships would have the advantage of being able to move from area to area in search of prime thermal gradients.

  Proposals and studies have been done on the production of hydrogen, ammonia, methanol, aluminum, titanium, and lithium from ocean energy systems. Ocean systems could also smelt and reduce deep ocean minerals. Hydrogen and oxygen can be produced directly from sea water. The hydrogen can be used in turn with nitrogen from the air to produce ammonia. It is very valuable as a basic chemical feedstock, as a fuel, and as an important ingredient in many fertilizers.(21)

Mechanical ocean energy systems are used to operate gongs, bells, and whistles on navigational buoys and have been proposed for desalination and powering barges.(12)(25)

OTEC systems can be used for *aquaculture* applications to pump nutrient-rich sea water to the surface as plant or animal food for raising seaweed, trout, salmon, Maine lobster, abalone, and strawberries, in addition to the system's electrical or mechanical power generation.(4)

TECHNOLOGY STATUS

Ocean energy has been used by man for different applications for centuries. There are records of tidal mills in Gaul, Andalusia, and England in the 11th century. Hundreds of tidal energy plants powered lumber and grist mills in colonial New England.(36) The concept of OTEC was first examined in 1881 by French physicist Jacques D'Arsonval and successfully tested by Georges Claude, a French engineer, in the early 1930s.(12) More inexpensive and simpler forms of energy minimized the development of ocean energy systems until the 1970s, when new research and development activities commenced in the U.S. and abroad in response to the energy crisis. Interest has decreased in the U.S. due to the declining price of oil, high capital costs, and environmental concerns, but activity continues in other areas of the world.

OTEC

Two basic designs have been developed for Ocean Thermal Energy Conversion: *closed-* and *open-cycle* systems. In addition, some combination and alternative systems are under consideration.

Closed-cycle systems have several advantages over open-cycle systems. Closed-cycle systems produce a higher vapor pressure, enabling them to use significantly smaller turbines than the large, low-pressure turbines of open-cycle systems. Ammonia high-pressure turbines suitable for OTEC applications have been developed in the refrigeration industry and are essentially state-of-the-art. The large, low-pressure turbines of smaller open-cycle OTEC systems will have to be adapted from existing technologies. Larger OTEC systems may require further advances in low-pressure turbines.

On the other hand, closed-cycle systems have several disadvantages. Closed-cycle systems require large heat transfer surfaces in the evaporators and condensers. Cost, corrosion, efficiency, and biofouling problems with heat exchangers have posed significant research challenges. The open-cycle turbine can be easier to design and build since it does not have to withstand high pressure. However, large negative-pressure vessels to house the evaporating and condensing sections will have to be built. Closed-cycle working fluids such as propane and ammonia pose potential handling and environmental problems and can pose material compatibility problems in the presence of sea water.

Argonne National Laboratory is working on a design that combines aspects of both closed- and open-cycle systems -- referred to as *latent-heat-transfer closed-cycle OTEC*. Their design flash-evaporates warm sea water under a vacuum and condenses the vapor against ammonia. The ammonia vaporizes to drive a turbine. This system has a number of potential advantages: it produces fresh water as a by-product at no cost to efficiency; it would not exhibit the usual biofouling and corrosion problems since the exchangers would contact only clean water vapor; it would require smaller turbines than traditional open-cycle systems; the design of the vacuum chamber would be simpler and more compact; and the problem of noncondensable gases in the water would be reduced. Detailed layouts and cost estimates have to be made before the design can be submitted to tests to determine its actual potential.

Since no commercial OTEC systems have been built to date, and experience on components is limited, costs cannot be estimated with a great deal of certainty. Many studies indicate that OTEC systems can provide energy at competitive prices, especially if additional revenue is gained from the sale of fresh water, or the production of materials.(7)

It presently appears that closed-cycle systems offer the greatest near-term potential for commercial OTEC plants. A successful proof of concept 50 kWe (gross) barge-mounted system was built in the late 1970s using off-the-shelf components. A 40 MWe (net) commercial-scale, closed-cycle plant has been designed and is planned for construction near Kahe Point, Hawaii in 1986. The plan calls for titanium shell-and-tube heat exchangers for evaporators and condensers with an ammonia working fluid. The cold water pipe will be 8,000 feet (2,500 meters) long to deliver 41°F (5°C) water from a depth of 2,300 feet (701 meters).(5) In order to evaluate the competitiveness of open-cycle systems in particular markets, the Solar Energy Research Institute (SERI) estimated the potential cost of electricity for a single stage direct contact OTEC system. The results indicate that mature OTEC systems could be competitive at sizes of 10 MWe and above in most markets. Plants in the 2-5 MWe range would be competitive in the U.S. trust territories and the Virgin Islands.(7)

Wave Energy

A broad variety of wave energy systems have been proposed, from the very simple and small scale, to the very complex and large scale -- on the order of several megawatts. Each has been championed by different groups and each has reached a different level of development. Most activity has occurred outside the U.S.

With the exception of small systems for navigational aids and two small power plants in Norway, wave energy systems are generally not commercial. Research is progressing on many of the designs, and laboratory models and prototypes have been built in some cases. The various designs can be roughly grouped in three categories: surface followers, pressure-activated devices, and focusing devices.

The most common *surface following* wave energy devices are *navigational buoys*. Simple direct mechanical systems cause a bobbing buoy to ring a bell or blow a whistle. More elaborate systems use the up and down movement to compress air in a vertical pipe. The compressed air is released through a turbine generating electricity to power lights. The Japanese have used 500 surface followers over the last 15 years. A computer system measures the wave pressure and triggers a latch that clamps the buoy to the shaft at the top and bottom of each stroke, creating a jerky motion instead of a smooth oscillation. This maximizes stroke amplitude, increasing power production. Testing of a 120 ton buoy indicated it could operate with a conversion efficiency of 80% and produce 300 kWe of power.(8)(12)

Other common surface followers include:

- The *Isaac's wave-energy pump* forces water out of a long pipe by the pressure created by the rise and fall of the float that supports the system in the water. If the water from a 500-foot-long (152 meters) pipe 3 feet (0.9 meters) in diameter is fed through a turbine, the system can generate 50 kWe in trade-wind seas.(29)
- A similar system, the *"Brystol cylinder"*, uses submerged air-filled vessels that move up and down with the waves. The energy of this motion is captured by a piston moving in a cylinder attached to the ocean floor.(12) The University of Delaware has developed a wave energy desalination pump that operates on the same principal. An oscillating float tethered to a pump produces hydraulic power to produce freshwater through reverse osmosis of ocean water.(29)
- The *Cocerell raft*, a relatively simple wave following device, consists of a row of rafts connected by hinges. As a wave passes the raft, hydraulic pumps activated by the hinges would extract energy from their relative motion. This system absorbs wave energy well, but the angular movement of the hinges is too small to generate power cost-effectively. The system is relatively easy and inexpensive to moor and has good resistance to storm damage.(29)
- The *"Salter Duck"* wave following design was developed in England and has been tested in Loch Ness. The duck consists of a row of cam-shaped lobes (beaks) that bob up and down with the waves. Internal hydraulics capture the energy of the rotating action and a turbine in the duck generates electricity from the hydraulic pressure. Initial economic studies indicate that electricity from a Salter duck-system would cost more than electricity generated by existing power plants. The high cost of mooring the system so that the backbone is rigidly fixed, and the complexity of the system contribute to its high costs.(12)(29) However, newer

versions of the system, utilizing single ducks, rather than strings, show promise of being significantly cheaper due to easier mooring.

Pressure-Activated Devices use the pressure of waves striking a stationary object to force volumes of air or water through a turbine.

- One promising type of pressure-activated device is *pneumatic systems* or *oscillating water columns*. Incoming waves strike the stationary system head on, causing the level of water in the interior column to rise. This rising column of water forces air out of the chamber at high-pressure through a turbine to generate electricity. As the wave recedes, the water column falls, creating a vacuum that pulls air back through the system. Systems have been proposed that will generate power throughout the cycle. These systems offer several advantages: they magnify low-density waves, are self-contained, have few moving parts, are relatively easy to moor, are not susceptible to corrosion since they use air rather than water, and are responsive to a wide range of wave heights, directions, and frequencies.(16)

A 5 MWe oscillating water column demonstration project has been proposed by a consortium of United Kingdom and European companies for operation by 1987. The system consists of four 49.2 feet by 49.2 feet (15 meter by 15 meter) columns and is expected to cost $16-18 million and produce energy at an estimated cost of 7.34¢/kWh.(13)(27)

Japan led a group of nations, including the U.S., Canada, Ireland, and Britain in producing a research vessel for testing various oscillating water column designs. The "Kaimei" is an 262.5 feet long (80 meters) with 22 chambers open to the sea. The total rated power in a typical sea was 2 MWe. The ship first began operations in 1978.(12)

Other oscillating water column systems include a 50 kWe test system built by Japan, and a 500 kWe system at Bergen, Norway.(8)(27)(29) The latter system uses a multiresonant oscillating water column (MOWC) to convert vertical wave motions in a 60 foot (18.2 meters) high chamber to compress air. The compressed air in turn drives a Wells turbine. This design is unique in its ability to maintain a high capture efficiency over a range of periods of the wave fronts, whereas previous designs operate efficiently only at wave front periods that are at or close to the resonant frequency of the oscillating water column. The potential cost of energy generated from this system is estimated to be 5.7¢/kWh.(37)

- The *floating air-bag* system, developed by the University of Lancaster (England), produces relatively inexpensive energy. A long, air bag is moored at right angle to incoming waves. Each wave squeezes the bag as it passes, producing high pressure air that is released through a one-way valve at the end of the bag to turn a turbine to generate electricity. A second valve readmits air at atmospheric pressure in-between waves. The system is not as efficient as some, but its simplicity leads to relatively inexpensive energy.(29) A more recent version of this design by Lancaster uses a ring of air bags to absorb waves coming from all directions. A 1/14 scale model was scheduled to undergo testing in Loch Ness in 1985.(8)

- A simple, but expensive system, the *triplate* wave energy converter produces hydraulic power from the differential motion of metal plates placed parallel to the waves. An incoming wave striking the front, movable, plate will push it toward the back, immobile plate, operating a pump which generates hydraulic power. A third plate serves to reduce secondary wave reflections between the plates that would counteract the effect of the original wave.

The simplest of wave energy conversion devices, yet those with the potential to produce large quantities of energy, are the various *focusing devices*. Each operates on the principal of condensing the power of the waves to make collection of energy simpler and more efficient. Two major types are being studied: wave catchers, and wave benders.

- *Wave catching* systems are the simplest. Natural features and manmade barriers are used to create a large funnel to direct waves into a narrow, steep channel. The concentrated wave pushes water to higher levels to spill into a catch basin. By concentrating the wave, its momentum is increased and the water reaches higher heights than normal. The water is then released through a turbine to generate electricity.(8)

  A 350 kWe plant is being built in Bergen, Norway. It is based on a tapered channel (Tapchan) that tapers from an entrance width of 0.65 feet (0.2 meters). The water is then raised to an elevation of almost 10 feet (3 meters) above sea level to a reservoir where it flows through a hydroelectric turbine. This plant is expected to generate electricity at a cost of 7.2 - 8.6¢/kWh. Designers plan to reduce this cost by 20% when the system is built to full scale.(37)

  A similar design is being developed for the African nation of Maritius. This project will be located at the country's Riambel Bay and have the capability to supply up to 20% of the island's electricity requirements. Two-thirds of all of the African nations have the potential for similar projects due to the continent's extensive coastline. A sloping cement wall will be built using a coral reef as the capture basin. The wall will be linked to the shore by sidewalls which will house the pumps/turbines that will power an on-shore electrical station. Waves washing into the newly created lagoon should offer favorable conditions for fish farming, mariculture and other spin-off projects.(37)

- *Wave bending* systems use physical barriers to alter the structure of the wave, changing it from a linear form to a curved form that converges at a point. These systems focus waves in a method similar to the focusing of light waves. Waves slow down as they come to shallow water. By placing a series of flat plates beneath sea level to create a false shallow bottom, a wave can be bent and focused on a point. The concentrated wave can be directed up a channel to a catch basin, as in wave catching systems. Focusing waves from a 6 mile (9.7 kilometers) coastline into about 1/3 mile (0.5 kilometers) will create waves 50 to 100 feet (15-30 meters) high that can reach a catch basin 300 feet (91 meters) above sea level. Such a system could produce between 100 and 250 MWe.(29) Alternatively, the concentrated wave could be fed directly up a chute and through a turbine.(12)

  A different wave bending system developed in the U.S. is called a *Dam Atoll*. This system uses a very large, slightly submerged dish-shaped structure to focus waves. A wave approaching from any direction will converge on the center of the dish as it is bent by the gradually rising convex surface of the system. The concentrated wave strikes vanes in the center of the dish that channel the water tangentially into a central chamber. The spiraling action of the water as it flows down through the chamber spins a turbine to generate electricity. A Dam Atoll 330 feet (100 meters) in diameter with a central chamber 35 feet (11 meters) in diameter and 65 feet (20 meters) deep would produce 4 MWe from 7 foot (2 meter) waves.(29)

Tidal Power

Most tidal plant concepts utilize traditional hydroelectric components: dams and turbines. The dam or impoundment restricts the flow of water in order to maximize the vertical height ("head") from which the water will flow through a turbine. The type of turbine best suited for the low-head characteristics (approximately 43 feet, or less than 13 meters) is the axial-flow, bulb-type turbine. The size of the bulb turbines is steadily increasing, and units are manufactured with runner diameters of 25 feet (7.5 meters), with capacities of 60 MWe.

The U.S. Department of Energy has funded design studies on an alternative system that uses a very thin plastic barrier rather than a solid dam. The "water sail" dam is supported by floats and as the system operates, the differential tide height is kept to approximately 6.5 feet (2 meters), producing pressures well within the margins of existing plastic membranes. The flow of water from the high side to the low side is used to compress air, which can either be used for the direct generation of electricity or can be stored for later conversion during peak power generation periods.(36)

As an alternative to building dams to tap tidal power, some studies have examined the possibility of siting large turbines in tidal currents to act like underwater windmills. Tidal currents run strongly in and out of some coves and represent a large source of kinetic energy. They would not require dams and would be dispersed over a wide area, thus presenting fewer environmental problems. The technology of such systems is not as far advanced as the hydroelectric turbines used in conventional tidal concepts.(11)

The U.S. has built no tidal energy systems, but a few design studies and economic analyses have been funded for plants in the Passamaquoddy Bay region in Maine.(1) The primary barrier to increased development of tidal power plants tends to be the large construction costs relative to the power output. However, many studies have indicated that tidal energy generation costs could be competitive with conventional technology if sufficient tidal range is available.(1)

The La Rance tidal power station, at the mouth of the La Rance estuary on the west coast of France, represents the world's first tidal plant, and it remains the largest. Construction began in 1961 and was completed in 1968. The system uses 24, 10 MWe generating units to provide an installed capacity of 240 MWe, and a net annual electricity production of 544 GWhe. The estuary has a tidal range of 44 feet (14 meters) and the

2,460 foot (750 meters) long dam creates a 8.5 square mile (22 km^2) basin, holding 6.35 billion ft^3 (180 million m^3) of useful water.(33)

The turbines ~~are~~ used to pump water to elevate the generating head and it generates on both the ebb and flow of the tide. The system could produce a gross generating output of 600 to 750 GWhe; however it is used primarily for peak power needs. La Rance is highly automated and is operated by only two men on evenings and weekends. A 20 kWe cathodic protection system has operated quite successfully in preserving the turbines from the corrosive effects of sea water, and the turbine blades were described as "virtually new" in 1984.(33)

A smaller system was built by the Soviet Union and began operation in 1968 in Kislaya Bay. The Kislogubskaya pilot plant consists of one 400 kWe generator.(1)(26) This installation pioneered floating construction techniques and avoided the use of coffer dams, typically the most expensive component of tidal power plants (accounting for 20% of the total cost of the La Rance project). Little else is known about the project.(1)(26)

The world's third tidal energy system is the Annapolis Tidal Power Project at Annapolis Royal, Nova Scotia, on the Bay of Fundy in Canada. It officially opened in August of 1984. The system was built on Hog's Island at the mouth of the Annapolis River at an existing dam built to prevent saltwater from surging onto fertile farm lands during storms.(26) The tidal range is between 14.5 and 28.5 feet (4.4 and 8.7 meters).(26) The plant was built to evaluate the feasibility of tidal generation in the Bay of Fundy and of the world's largest Straflo (straight flow) turbine. This new turbine has a short drive shaft that requires less space, and thus less concrete for the dam. If it proves successful, it could save 10-15% in construction costs on a larger system.(34) The 25 foot (7.6 meters) diameter axial flow, bulb type Straflo turbine will provide a generating capacity of 17.8 MWe at an operating head of 18 feet (5.5 meters) and will generate an estimated 50 GWhe annually.(35)

The cost of the Annapolis Royal plant was approximately $53 million, or $2650/kW (installed).(31) The cost of the generated electricity was projected to be 2.7¢/kWh.

GOVERNMENT SUPPORT

Federal research and development support for ocean energy systems comes from the Ocean Energy Technology Division of the Office of Conservation and Renewable Energy, U.S. Department of Energy. For Fiscal Year 1985, the ocean energy research and development budget was $4.48 million, a 19% drop from Fiscal Year 1984 (see TABLE 5-1 and FIGURE 5-3).

TABLE 5-1

U.S. DEPARTMENT OF ENERGY FUNDING FOR OCEAN ENERGY RESEARCH AND DEVELOPMENT, BY PROGRAM
($ millions)

	FY83	FY84	FY85
Thermodynamic Research	2.09	3.30	1.65
Environmental and Oceanographic Research	0.76	0.50	0.15
Materials and Structures Research	1.89	---[a]	0.58
Experimental Verification and Testing	0.75	1.70	1.80
Engineering Development	5.00	---[b]	----
Wave Energy	----	----	0.30
Total	10.49	5.50	4.48

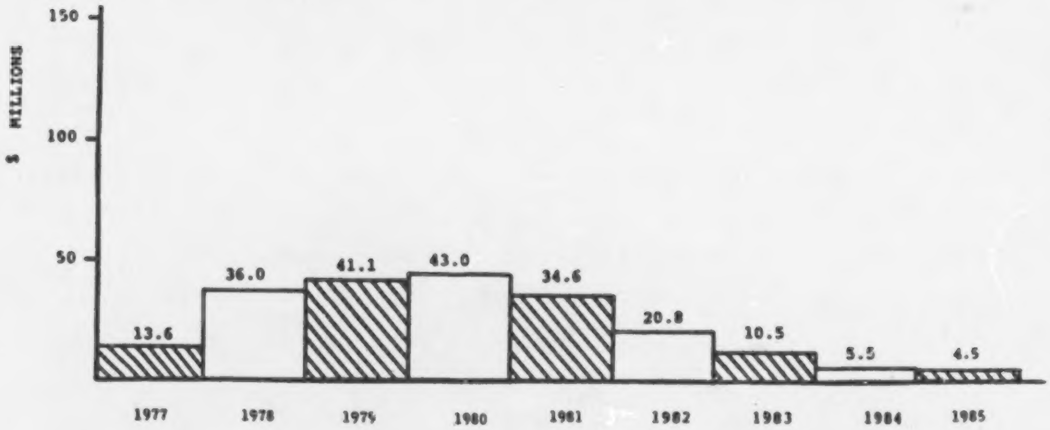
Note: Includes research on waves, currents, and salinity gradients, as well as OTEC. Over 96 percent of the funding was for OTEC through 1981.(24)

Sources: Renewable Technologies Program Summaries. Deputy Assistant Secretary for Renewable Energy, U.S. Department of Energy (DOE/CE-0105), November 1984, pp. 60-65.

U.S. Department of Energy FY86 Congressional Budget Request: Energy Supply Research and Development--Solar and other Renewables, p. 70.

FIGURE 5-3

U.S. DEPARTMENT OF ENERGY FUNDING FOR OCEAN ENERGY RESEARCH AND DEVELOPMENT, FY 1977 - FY 1985



The Public Utility Regulatory Policies Act (PURPA) requires utilities to buy electricity generated by non-utility small power producers at the utilities' avoided cost rates. Ocean energy systems of less than 80 MWe of installed capacity qualify under PURPA.

Additional government support occurs under a U.S. law enacted in 1980 which allows OTEC plants and plant-ships to be considered "vessels." This makes OTEC plants and plant-ships eligible for federal mortgage loan guarantees that were once available only to more conventional merchant vessels. Moreover, the law provides a streamlined, one-stop licensing process for OTEC plants. The Office of Minerals and Energy under the National Oceanic and Atmospheric Administration in the Department of Commerce oversees this process.(38)

A 15% federal business energy tax credit for investments in ocean energy systems, and a 40% residential energy tax credit (limited to $4,000 or 40% of a $10,000 investment) expired at the end of 1985. Five states offered various incentives for the development of ocean energy systems (see APPENDIX I).

INDUSTRY STATUS

OTEC

There are no commercial OTEC systems in operation or under construction; however, there are a few private U.S. companies actively pursuing the technology in hopes of building commercial systems.

An international consortium of companies is in the advanced stages of planning for the world's first commercial OTEC plant. Based on its pilot plant work for DOE, the consortium submitted a request in 1984 to 7 groups of companies asking for bids on the construction, operation, and ownership of an OTEC plant of approximately 50 MWe. The French and Japanese are involved in at least two of these groups. The consortium expects that the final design and permitting and licensing process will take a year or two and the construction an additional two years, so preliminary plans are to have the plant in the water and producing power by the end of 1988.

No other company, or group of companies is as far advanced but a few engineering and naval architecture firms are actively involved in feasibility studies for foreign clients to evaluate the technology's potential. Pending the outcome of these studies, these firms could become involved in developing OTEC plants. A smaller number of research firms are working on OTEC equipment and hope to be involved in designing complete systems or supplying components.

A variety of companies have been involved in OTEC research in the past, primarily supplying products and expertise in OTEC components. These include marine construction companies, heat exchanger manufacturers, power system manufacturers, and chemical companies. Of these companies, some are involved in the bidding on the pilot plant project, while others remain interested in the technology and can supply their expertise to other commercial projects.

Wave Energy

There are no suppliers of commercial wave energy systems yet, since the technology is still in the early stages of development.(1) Most research has been funded by governments and universities. Once the technology is demonstrated, any of a number of companies could enter the market, including spin-off companies from universities and government research labs, small manufacturers dedicated to ocean energy, traditional broadly-based manufacturers, and engineering companies.

A consortium of United Kingdom and European companies led by Scottish firms have tentative plans for installing and operating a 5 MWe Breakwater plant off the west coast of Scotland by the summer of 1987. The same team is considering four other possible installations, including a 30 MWe system in the West Indies and a project for a remote community in Oregon.(27)

Tidal Energy

There is no industry dedicated to building or installing tidal energy systems, but suppliers for all the major components exist. Government sponsored projects will draw from existing expertise in conventional hydroelectric and marine heavy construction firms. Engineering and construction firms exist with the requisite knowledge and experience to construct tidal energy systems. Turbine design and fabrication services are available from traditional hydroelectric suppliers.

MARKET STATUS

Ocean energy installations to date have largely been experimental or demonstration systems. Few commercial wave and tidal installations exist, and a commercial OTEC installation has yet to be built. The market for ocean energy systems can therefore be described as a potential market, not a developed market. In the near term, the primary market for ocean energy systems will likely be power production in remote areas (e.g. small islands and isolated communities), although the first systems may be connected to the grid while the technology is becoming established. If systems prove reliable and economical, a large potential market exists for offshore manufacturing and chemical processing using floating plantships.

In the longer term, a market could develop for central generation systems. Current utility overcapacity in the U.S. limits the near term market for utility-owned central generation facilities, particularly capital intensive ones.

OTEC

The nearest-term opportunity for OTEC systems in the U.S. will be for electricity generation systems tied into the electric grid. Estimates for how much energy is available from ocean thermal energy conversion in the near term for the U.S. vary widely. It has been estimated that from 3,000 to 10,000 MWe of generating capacity is practically achievable by the year 2000. An estimated 20,000 to 40,000 MWe could be installed by 2025.(24)

Worldwide, OTEC systems could provide a large portion of baseload electricity for small islands in tropical regions. For industrialized nations other than the U.S., the potential OTEC market is 245,000 MWe. The potential market in developing countries is an additional 50,000 MWe.(38)

Some OTEC systems will produce fresh water as well as electricity. In regions where fresh water is scarce, these systems can significantly augment their income through the sale of fresh water. When such sales were taken into account, the economics of open-cycle OTEC systems appear even more attractive.(7)

OCEAN ENERGY

Wave Energy

The nearest term market for wave energy systems is probably remote power, and perhaps electrical generation tied into the utility grid. Given the current status of the many wave energy systems, it is too early to estimate the total power production potential. Power systems for buoys and communication equipment will continue to develop but will not constitute a large market.

Tidal Energy

Based on experience at Annapolis Royal, Canadian studies are underway to built a full-scale plant in the Bay of Fundy capable of generating 5,000 MWe.(31) Many other feasibility studies have been done to install large systems in the Bay of Fundy. In 1979, the U.S. Army Corps of Engineers reported on approximately 90 alternatives with sizes ranging from 5-450 MWe. Construction costs ranged from $22 million to $916 million.(36) Numerous studies have also been done for systems in other countries, including the three countries with functioning systems (France, the U.S.S.R., and Canada) and other countries with promising tidal resources, including South Korea, England, Australia, and Argentina. Of these countries, the most active are South Korea, France, and Canada.(36)

OCEAN ENERGY

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Chapter 6

SOLAR RESOURCE AVAILABILITY

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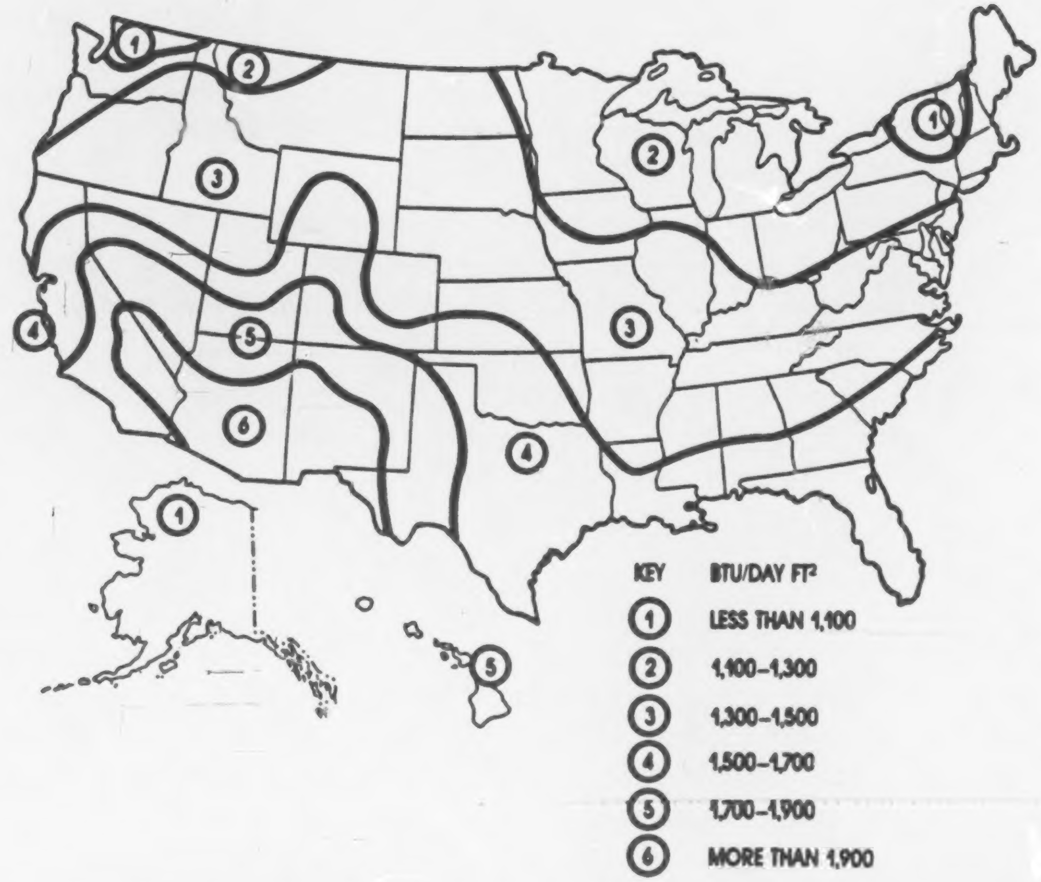
SOLAR RESOURCE AVAILABILITY

The Solar Resource Base

Energy from the sun (solar insolation) represents a potentially enormous source for a variety of end-uses. Direct use of the sun's light and thermal energy has long been recognized. More recent application of the resource (e.g. concentrating solar thermal energy and photovoltaics) have expanded its potential use enormously, yet the total resource availability makes solar energy one of the earth's most abundant energy source. The equivalent of 180 trillion kilowatts of solar radiation strikes the earth, far more than the 672 million kilowatts of U.S. electric capacity in 1984 (see FIGURE 6-1).(1)(2) Yet the earth's share of the sun's solar radiation is only one 200-millionth of the sun's total energy.(1)

The daily and seasonal variations in solar energy resources are responsible for the creation of other renewable energy resources, e.g. wind, flowing streams and rivers, photosynthetic production of biomass, and thermal gradients in the ocean. For these reasons, the solar energy resource base is often expanded to include these other resources. For information about the availability and distribution of wind, biomass, and ocean energy resources, see the RESOURCE AVAILABILITY section of those particular chapters.

FIGURE 6-1
SOLAR INSOLATION IN THE U.S.
(BTU/Day per ft^2)


KEY
BTU/DAY FT²
① LESS THAN 1,100
② 1,100–1,300
③ 1,300–1,500
④ 1,500–1,700
⑤ 1,700–1,900
⑥ MORE THAN 1,900

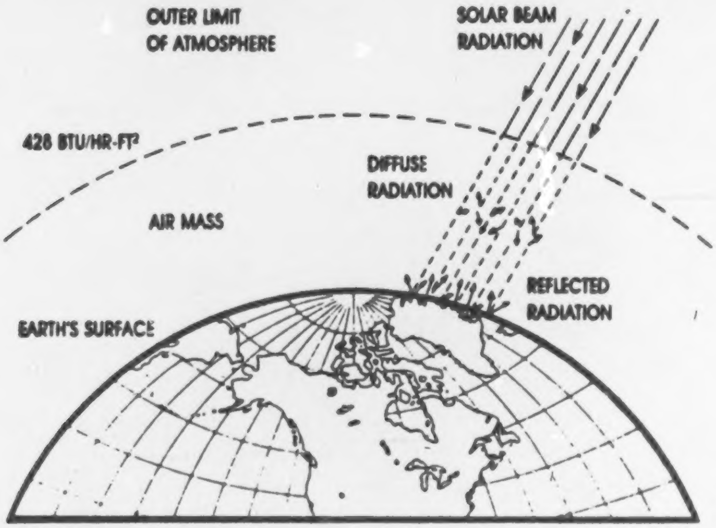
Source: David Miller and Grant Price. Solar Water Heating: A Guide for New Mexico Homeowners. Las Cruces: New Mexico Solar Energy Institute, p. 7.

Characteristics of Solar Energy

The amount of solar radiation striking the earth is called *insolation*, measured in British Thermal Units (BTUs) per square foot (ft^2) per hour, or watts per ft^2 per hour. A significant portion of this radiant energy does not reach or is not absorbed by the surface of the earth, though. Three factors cause this: the albedo effect, atmospheric composition, and the distance of the atmosphere through which solar radiation must pass to reach the earth's surface (see FIGURE 6-2).

FIGURE 6-2

EFFECTS OF THE EARTH'S ATMOSPHERE ON INCOMING SOLAR RADIATION



Source: David Miller and Grant Price. Solar Water Heating: A Guide for New Mexico Homeowners. Las Cruces: New Mexico Solar Energy Institute, p. 6.

The *albedo effect* refers to the reflection of energy from an object. In this case, part of the incoming solar radiation is reflected back into by clouds, atmospheric particles, and to a lesser extent, by sand, water, and snow on the earth. As much as 35% of incoming solar radiation is not absorbed by the earth's surface because of this phenomenon.(3)

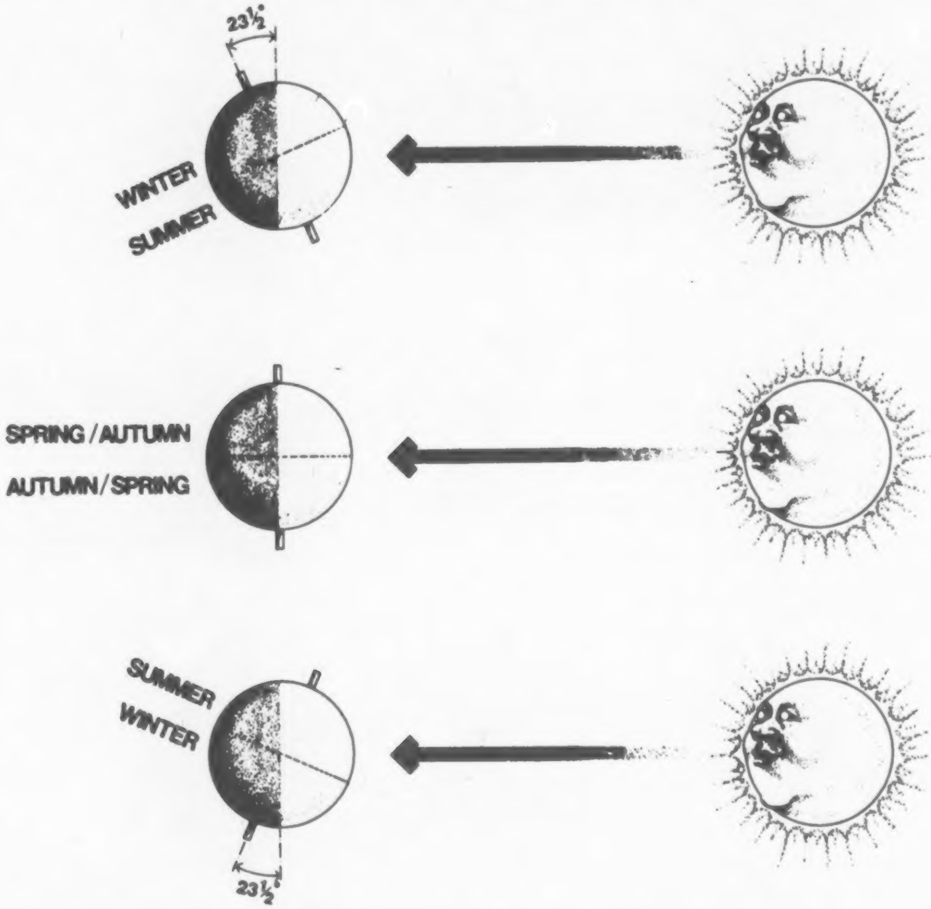
Atmospheric elements also affect the amount of incoming solar radiation. Water vapor, carbon dioxide, and ozone, absorb as much as 10-15% of earth-bound solar radiation. Furthermore, solar radiation can also be reflected, or "scattered" by air molecules and dust particles, resulting in *diffuse* solar radiation. Diffuse solar radiation is responsible for the blue color of the sky.(3)

Besides atmospheric absorption and diffusion, the most important determinant in the amount of solar radiation reaching the earth is the length of the atmosphere through which the sun's rays must travel. Solar radiation passes through the least amount of atmosphere when the sun is directly overhead. The distance increases as the sun moves closer to the horizon (sunset and sunrise). The more atmosphere or air mass solar radiation must pass through, the less its energy content due to increased absorption and scattering.

The atmospheric length varies not only by time of day but by time of year, due to the earth's tilt and its rotational axis. As the earth orbits the sun, it rotates once daily along an axis that extends from the North Pole to the South Pole. The axis is tilted slightly (23.47°) from a vertical to the plane of the earth's orbit around the sun. The tilt of the earth's axis accounts for the seasonal changes in weather (see FIGURE 6-3).

FIGURE 6-3

HOW THE EARTH'S TILT AFFECTS THE SEASONS



Source: Edward Mazria. The Passive Solar Book. Emmaus, PA: Rodale Press, 1979, p. 12.

SOLAR RESOURCE AVAILABILITY

Energy from solar radiation has many features that make it an attractive energy source: its global distribution, its high thermodynamic quality, its virtually inexhaustible supply, and its availability in the same form and quality over time. On the other hand, some characteristics have limited the widescale application of solar energy. The daily and seasonal variations in available sunlight may require the use of energy storage facilities, or to combine it with other energy forms in a hybrid system. Also, the dispersed nature of the resource itself affects economical power generation. The average amount of solar energy striking an area, including direct and diffuse radiation, can vary from 21.4 kilowatt hours (kWh) per ft^2 (2 kWh per square meter [m^2]) in northern Europe to as much as 75-85 kWh/ft^2 (7-8 kWh/m^2) in sunny, arid regions.(4) It is the latter areas where power-generating solar systems are currently being installed, and where they are most likely to achieve significant market penetration.

Passive Solar Design

Solar energy has long been recognized for its thermal properties. Residential or commercial buildings can be specially designed or retrofitted to use solar energy directly to meet daily heating, lighting, and/or cooling requirements. These processes, referred to as *passive solar design* have potential for reducing space heating and cooling, as well as lighting demand. Passive solar designs could potentially be in 30% of all new homes constructed in the U.S. by the year 2000.(5) Another source estimates the energy contribution from passive solar design to be 0.4 quads in the year 2000.(7) If met, this would supply 2% of the projected residential and commercial sector's energy needs.(6) Worldwide, between 50-100 million buildings may be using passive solar design by the year 2000.(5) If this latter estimate is realized, the fuel required to heat, cool, and light the world's buildings could be reduced by 25%.(5)

Solar Heating and Cooling

Solar heating and cooling also has great potential. A growing number of building owners and operators have recognized the potential of designing collectors to optimize the thermal properties of the sun's radiation. Hot water, heating, cooling, and industrial process heat needs can be achieved by solar collectors placed on the roof or attached to a residential or commercial building. In the U.S., 0.2 quads of energy could by supplied by solar heating and cooling systems in the year 2000.(7) If realized, 1% of the projected demand of the residential and commercial sector would be met by solar heating and cooling systems.(6) Worldwide, approximately 5 quads annually could be provided by solar heating and cooling systems.(5)

Photovoltaics

Solar radiation is currently being used to generate electricity via two technologies: photovoltaics and solar thermal. Photovoltaic systems generate electricity directly by solar cells made from semiconductor materials. The relative simplicity, the lack of moving parts, and the promise of little or no maintenance make photovoltaics an attractive solar technology. A Department of Energy estimate predicts photovoltaics will contribute 0.3 quads by 2005 and 0.7 quads by 2010.(6)

Worldwide potential photovoltaic capacity is difficult to assess, but it could be substantial. One estimate is 1,000 MWe by 1990 and between 5,000-20,000 MWe by the year 2000.(5) The latter figure would produce only about 0.4 quads. By the middle of next century, it is estimated that photovoltaics may provide about 20% of the world's electricity demand, or approximately 20 quads. This would require approximately 1 million MWe of photovoltaic capacity in the form of centralized power plants and systems installed on top of buildings and/or dwellings.(5)

Solar Thermal Energy

Concentrating solar thermal systems--parabolic troughs, parabolic dishes, central receivers, and hemispheric bowls--convert solar radiation to thermal energy, which can be used directly or sent through a turbine to generate electricity.(8) Concentrating solar thermal systems are capable of producing high temperatures (750°F-1500°F) and can be connected to low-cost thermal storage. This combination makes concentrating solar thermal systems a promising solar technology for medium-to-high temperature industrial process heat applications, chemical and fuel production or processing, and baseload or peaking electricity generation.

Estimates of the potential concentrating solar thermal contribution to U.S. energy supply are not widely available. One estimate predicts that 0.4 quads per year of electricity and 2.6 quads per year of thermal energy will come from concentrating solar thermal systems by the year 2000.(8) If achieved, this would account for about 2-3% of the projected U.S. electricity, and 8% of projected U.S. industrial process heat demand.(8) Another source predicts solar thermal systems will contribute 0.1 quads by 2005.(6) There are no known worldwide estimates on future concentrating solar thermal capacity.

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Chapter 7

PASSIVE SOLAR DESIGN

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PASSIVE SOLAR DESIGN

TECHNOLOGY DESCRIPTION

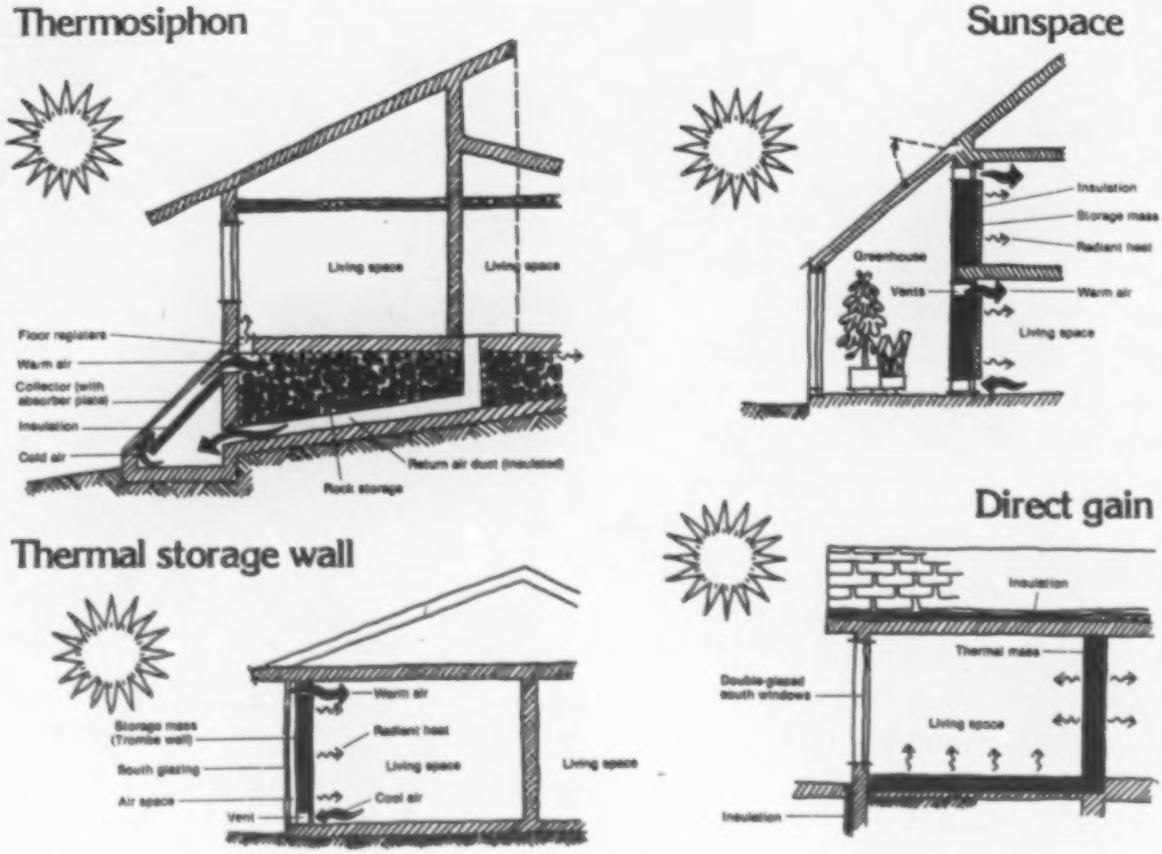
The term "*passive solar*" encompasses a wide range of strategies in designing and constructing buildings in order to take advantage of the sun's energy and the surrounding environment, thus reducing or eliminating a building's need for conventional energy. Passive solar design uses very few, if any, mechanical devices. The building itself collects, stores and uses solar energy, and is designed to take advantage of site specific features for natural heating, cooling and lighting. By contrast, "*active solar*" encompasses independent systems, including components such as roof collectors, pipes, pumps and tanks used to capture the sun's energy for water and space heating needs (see *SOLAR HEATING AND COOLING*).

A complete *passive solar heating* system will include collection of energy, through south-facing glass; storage of energy, through the use of thermal mass, usually in the form of concrete, brick, water or phase change material; regulation of energy, which may be as simple as providing overhangs, shades or other insulating material for windows, or providing a door to close off a sunspace at night; and distribution of energy, which usually consists of vents, dampers duct work and small fans. The three most common passive solar heating systems are:

- *Direct Gain*. In this system, the sun shines directly through south-facing windows, into the space to be heated. Thermal storage is provided to absorb and store the energy, and to prevent overheating on sunny days (see FIGURE 7-1). Good direct gain designs include well conceived shading controls, such as overhangs, blinds, and vegetation to reduce unwanted solar gain. Suntempering is a relatively low-cost direct gain technique which uses a normal amount of windows but simply locates most of them on the south side.

FIGURE 7-1

TYPES OF PASSIVE SOLAR DESIGNS


Thermosiphon
Living space
Living space
Floor registers
Warm air
Collector (with absorber plate)
Insulation
Cold air
Return air duct (insulated)
Rock storage
Sunspace
Insulation
Storage mass
Radiant heat
Greenhouse
Vents
Warm air
Living space
Thermal storage wall
Warm air
Storage mass (Trombe wall)
Radiant heat
Living space
Living space
South glazing
Air space
Cool air
Vent
Direct gain
Insulation
Thermal mass
Double-glazed south windows
Living space
Insulation

Source: "Passive Solar: How it Works," Builder, May 1, 1981, pp. 19-22.

- *Indirect gain.* This system generally uses a mass wall (Trombe wall) or a water wall directly behind the south-facing glass, separated by a small airspace. The Trombe wall is usually built of concrete, brick or stone, while the water wall is usually constructed of plastic or metal framing. Solar energy strikes the wall and is absorbed and stored for re-radiation into the living space (see FIGURE 7-1).

  Phase change materials, which release heat ass they change form (e.g., from a liquid to a solid state), are also employed in indirect systems. Phase change materials can be incorporated into concrete, brick or stone walls, or even into household furniture.

Another popular indirect gain system is a sunspace attached to the south side of a building but separated by a common wall. Distribution of sunspace heat to the house is by natural convection of air through open doorways which are then closed at night (see FIGURE 7-1).

- *Isolated gain*. Energy is collected and stored in a space "isolated" from the rest of the house, commonly in an attic or greenhouse. The energy is stored in the thermal mass of floors or walls, or in phase-change materials, and redistributed when needed, usually via fans or ductwork (see FIGURE 7-1).

Passive cooling techniques for building design are perhaps better labeled as natural cooling mechanisms, in that they require no pumps or fans for their operation. Methods of passive cooling include heat avoidance (e.g. the use of operable shades, overhangs, awnings, and surrounding vegetation); ventilation (using natural air flows and breezes by creating an opening on opposing sides of a house or room, or using the "stack" or "chimney" effect where convective air flow is induced through the use of cupolas, attic vents, belvederes, wind vanes, and wind scoops); evaporative cooling (using roof sprays or ponds, or indoor bodies of water); radiational cooling (using unobstructed horizontal roof or ceiling glazing to take advantage of clear, nighttime "sky" radiation); thermal mass (interior mass that is ventilated to release accumulated heat); and ground cooling (earth berming, earth tubes or building underground).

The use of *natural lighting* or *"daylighting"* to reduce a building's energy load is another passive solar design technique. Some of the most common are light shelves; a reflective device, usually located within a window, which reflects and disperses sunlight onto ceilings and walls; a clerestory, an upper extension of a wall pierced with a window to admit light and air; roof monitors, raised sections of a roof with openings, louvers or windows (not parallel to the roof plane) used to admit light and air; and skylights, the familiar glazed roof apertures which are located along the roof plane. Atrium and ordinary windows, if properly designed and located, are other effective daylighting options. Indoor lighting can also be enhanced by combining daylight with artificial lighting control systems.

APPLICATIONS

Passive solar energy has made inroads into the design of single and multi-family residential dwellings, institutional and commercial buildings.

Residential buildings (single and multi-family) are considered "skin-load dominated", which means energy use depends, in large part, on the building exterior envelope--how well it protects against heat or cold, how well-insulated or well-sealed it is against air infiltration. Because of this, the best or most cost-effective designs are a balance between passive solar features and energy-conservation techniques.

Institutional and commercial buildings, on the other hand, are considered "internal-load dominated", because of low surface-to-volume ratios and heat generated by lighting, equipment, and people. Because lighting represents 25-50% of most commercial buildings' energy use, daylighting may be the biggest opportunity for passive solar design.

TECHNOLOGY STATUS

Passive solar design has been used since the ancient Greek and Roman civilizations. The cities of Olynthus in Greece and Priene in Asia Minor oriented city streets north-to-south and east-to-west to give houses a direct southern exposure. Roman Empire courts wrote solar access laws to guarantee a citizen's right to direct sunlight. Pueblo Indians in the southwestern United States built passive solar communities long before the Europeans arrived.(3)

The use of passive solar design in modern times has been infrequent. In the 1930s and 1940s, George and William Keck created several passive solar designs that won widespread public attention. Their design for Chicago real estate developer Howard Sloan attracted 5,000 visitors in three months, and Sloan responded by building a solar development in suburban Chicago. However, the availability of inexpensive energy sources limited the development of passive solar design after World War II.

Interest in passive solar design revived in the 1970s, due to the energy crisis of 1973. By the late 1970s, the publication of several books on passive solar design helped establish the inexpensive, do-it-yourself tone that accompanied passive solar design and construction technology at that time.

Passive solar design technology has appeared simple but involves complex physical and thermodynamic principles to collect solar energy, store it as heat, distribute heat and light to where it is needed, while minimizing heat loss to assure there is a balance between net heat gain and heat required.(1) Unlike conventional heating and cooling equipment which are added to a building to serve a specific function, passive solar features are usually integrated into a building design in a way that almost defies their separation. In a good passive solar design, every component of a building serves multiple functions, be it shelter, heating, cooling, daylighting, heat storage or distribution.(2) Incorporating effective energy conservation techniques like insulation, caulking, double- and triple-pane windows, thermal shutters and storm windows greatly enhances a dwelling's thermal efficiency, consequently reducing the thermal requirements of the passive solar features.

Different passive solar designs are used for different types of buildings, depending on their specific energy requirements. Residential homes use most of their energy for heating, especially in colder climates. Passive solar homes have been designed to provide all of the heating requirements. However, many temperate climate designs use November and March as design months to avoid overheating in summer, requiring the incorporation of auxiliary heating systems. Commercial buildings consume most of their energy in lighting and cooling. In commercial buildings, passive solar design emphasizes daylighting by using skylights and atriums. It is estimated that most passive solar systems provide between 30-70% of a residential home's energy needs and between 20-30% of a commercial building's energy requirements.(4)(37) It is generally assumed that conservation and passive solar features add 5-10% to the cost of a building.(2)

The recently released results of a monitoring program, conducted since 1978 by the U.S. Department of Energy (DOE) and the Solar Energy Research Institute (SERI), for 70 homes in various climates provide some general performance characteristics of passive solar designs.(30)

- Passive solar homes use 70% less auxiliary heat than conventional homes, with the average solar contribution being 37% of the total heating load or 55% of the net heating load (total load minus internal gains). Passive solar houses with greater daily temperature swings 10-15°F, as compared to 5°F in conventional homes, still required less auxiliary energy.(30)
- The comfort of passive solar homes can also be greater than conventional homes. Of the homes monitored, the average indoor temperature was 67°F. Because the heat is supplied by radiation (mean radiation temperature), this temperature is equivalent to 74.2°F in air temperature.(30) A 1°F change in mean radiation temperature is assumed to have a 40% greater effect on body heat loss than a 1°F change in air temperature.(36)
- Of the various systems employed by the passive solar homes (direct gain, indirect gain, and isolated gain), there was no noticeable difference in performance among them. In fact, many of the houses used combinations of one or more solar options to good advantage.

Heating

Collecting solar energy through passive solar design can be as easy as allowing the sun's rays to penetrate a window: short-wave ultraviolet enters the space, while reradiated long-wave infrared is contained. However, common glazing materials, such as single-pane windows, have poor insulating qualities and usually lose more heat than they gain. The introduction of insulated glass in the 1940s helped solve this problem, but at the expense of a small decrease in solar transmittance (percentage of solar radiation passing through the glazing).(6)(7) Consequently, research is proceeding on maintaining good insulation qualities without sacrificing solar transmittance (see Glazings).

In direct gain passive solar systems, materials used for thermal storage are often those used in constructing the building, such as concrete, brick, or stone. These materials absorb the heat from solar radiation and release it at night or on cloudy days when the temperatures decrease.(20) Water is also an excellent means of storing heat, and some simple passive solar systems have used glass jugs, bottles, or plastic containers filled with water located close to windows as means of thermal storage. Several companies have produced more attractive means of storing water, such as translucent tubes, or containers that will fit inside the framing cavities in walls and floors.(1)

Indirect gain systems use Trombe walls made of stone, brick, or concrete which are located directly behind solar-collecting windows. Trombe walls avoid glare, overheating, and damage to fabrics and wood that can occur with direct gain systems. Small vents at the top and bottom of the Trombe wall are sometimes used to assist in heat distribution. Trombe walls can be unvented if nighttime heat is the primary need of the passive system.(26)

Cooling

Natural cooling is another example of using simple building techniques in passive design. Avoiding or reducing heat gain is an important part of passive cooling. This can be accomplished through the use of awnings and shades or planting vegetation to provide shade. Placing a low-emissivity material, such as aluminum foil, underneath the roof can block 95% of the sun's heat from penetrating the building. This reduces the amount of energy used for cooling in residential buildings by 8-14%.(19) Ventilation can be encouraged by proper location of windows and by installing wing walls perpendicular to the main walls. This creates a pressure difference between the windows, providing an air flow. Studies have shown the addition of wing walls can increase ventilation by 100%.(22) Cool air can be piped in from underground tubes located 6-10 feet below ground level. However, design and sizing of earth tubes are still at an early stage.(23) Ice ponds (large piles of ice) that are accumulated during winter months can provide summer cooling by circulating the cold water through heat exchangers. While ice ponds may be uneconomical to size for single family dwellings, they can be applied to commercial and industrial facilities for hospitals and meat packing plants with large cooling loads.

One combined passive solar heating and cooling concept is the "air core" system.(29) A wall and/or floor of concrete blocks are used with their cores lined up creating an air channel. The air cores may be lined with an impermeable lining to eliminate moisture transfer from the ambient air through the concrete wall. An insulated curtain or shade blocks summer sun or keeps winter heat inside when it is lowered. A fan, which can be controlled by a thermostat, is installed under the floor or in the eaves to distribute the warm or cool air. This system can be used for both commercial and residential buildings, and supply 50% of a building's cooling and heating needs in certain climates.(27)

Lighting

The use of skylights, atriums, clerestories, and light shelves can help reduce a building's total energy consumption by 20-30% while aiding in heating and cooling functions.(35) Since daylighting cannot supply all of the lighting required in most cases, it is important to select a light control system that will turn on artificial lighting only when needed and turn it off at other times. Several control strategies can be employed:

- *Switching systems* turn the lights off automatically when the natural lighting level equals or surpasses the desired level.
- *Ideal dimming* lowers artificial lighting as natural daylighting increases, shutting off when daylight is at the desired level.

- *Occupancy sensor systems* use motion-sensing sound waves or infrared radiation to turn on lights when a room is occupied. Commercial office buildings have reduced their energy loads up to 45% using this system.(35)

Sunspaces

Houses can be retrofitted or specially designed to incorporate sunspaces (e.g. greenhouses and solariums). In general, sunspaces are south-facing rooms with large windows or glazings and thermal mass that assist in the heating and cooling of the house. Air circulates by convection or through the use of fans. The thermal mass may be masonry walls, phase change materials, or materials used in constructing the floor (e.g., concrete, brick, or stone).(30) Sunspaces can be specially designed and built or purchased as a prefabricated kit that costs \$60-100 per ft^2 (\$645-1076 per m^2).(31) In sunny climates like New Mexico, sunspaces can provide between 10-70% of a home's heating requirements, yet sunspaces can be energy losers if not well insulated.(37) Overheating can also be a problem, especially if using sloped or overhead glass, a popular feature for many restaurants and residences.(1)(28)

Storage

Thermal energy storage in many passive systems is accomplished by using water-filled containers or a thermal mass of concrete, brick, stones or adobe. Each material has different heat storage capabilities, depending on their specific heat (the number of BTUs needed to raise the temperature of 1 pound of a material 1°F), and the material's heat capacity (the amount of heat that can be stored in a cubic foot of a material for a 1°F temperature rise). Properly choosing a heat storage medium depends on where it will be located, the type and size of the container to be used, and how much heat energy is needed. TABLE 7-1 presents the specific heat and heat capacity properties of a few common heat storage materials, along with their densities.

TABLE 7-1

PROPERTIES OF COMMON HEAT STORAGE MATERIALS

Material	Specific Heat ($Btu/lb/^{o}F$)	Density (lb/ft^3)	Heat Capacity ($Btu/ft^3/^{o}F$)
Water	1.00	62	62
Scrap Iron	0.12	490	59
Scrap Aluminum	0.23	170	39
Concrete	0.23	140	32
Stone	0.21	170	36
Brick	0.20	140	28

Source: Bruce Anderson and Michael Riordan. The Solar Home Book. Andover, MA: Brick House Publishing Co., Inc., 1976, p. 184.

An alternative to these materials is *phase change materials* . Phase change refers to the process of changing a substance from one form to another form (e.g. liquid to solid). In passive solar systems, the heat from solar radiation melts the solid phase change material. As the temperature drops, the phase-change material solidifies, releasing heat. Phase change materials can store 4 times more heat per unit of volume than water and take up less space than air or liquid storage.(1) However, problems have occurred in finding containers that will not leak and phase change materials that will remain stable and be able to repeat the melting/freezing cycle indefinitely.(1)

Glazings

Another area of passive solar component research is focusing on window glazings. The glass industry is experimenting with the placement of low emissivity (low-e) coatings on window glass, combining high solar transmission with good insulating characteristics.(1) Two types of coated low-e glass are available: soft-coat and hard-coat.

- *Soft-coat* is made by striking a metal bar with electrons, causing the bar to release atoms from the metal. The atoms are then condensed onto a cold surface like glass in a vacuum environment. Soft coat has better insulating and solar transmission properties than hard coat. Research is focusing on increasing its shelf life and easing current difficulties in handling and shipping.(5)(6)(7)

- *Hard coat* is made by spraying a hot, metallic oxide onto hot glass. As the glass cools, the metallic oxides hardens, thus its name "hard coat." Although hard coat cannot match the energy performance of soft coat, it can be handled, cut and stored like regular glass, and it has an unlimited shelf life.(5)

Switchable glazings change their reflectivity upon exposure to different light (photochromic), heat (thermochromic), or electrical (electrochromic) stimuli. Several different private and public research projects are being conducted on electrochromic materials.(9)

Solar Design Tools

Perhaps the biggest obstacle to passive solar design is simply transferring the technology from the laboratory to the marketplace. Passive solar designs are not easily standardized; what may work in one area may not work elsewhere, due to differences in solar insolation, climate, and heating and cooling requirements. Different techniques are being tried to educate builders and the public. The "passive solar building design sheets," developed by the Los Alamos National Laboratory in New Mexico, advise the builder which passive solar technique to use, depending on what materials are to be used in building, the thickness of the walls, the site's climate, how many BTUs per square foot the builder desires, and how much the building will cost to construct. A new design sheet is now being applied for Raleigh, North Carolina.(18)

At least 10 different computer programs now exist to aid designers in optimizing the passive solar components of a building.(4) Although most focus on heat gain and loss in residential buildings, three of these are intended for daylighting applications in commercial buildings.(33)

GOVERNMENT SUPPORT

Federal research and development support for passive solar comes from the Solar Buildings Division of the Office of Conservation and Renewable Energy, U.S. Department of Energy. For Fiscal Year 1985, the passive solar research and development budget was $6.54 million, a 38% reduction over Fiscal Year 1984 (see TABLE 7-2 and FIGURE 7-2).

TABLE 7-2

U.S. DEPT. OF ENERGY FUNDING FOR PASSIVE SOLAR RESEARCH AND DEVELOPMENT, BY PROGRAM
($ millions)

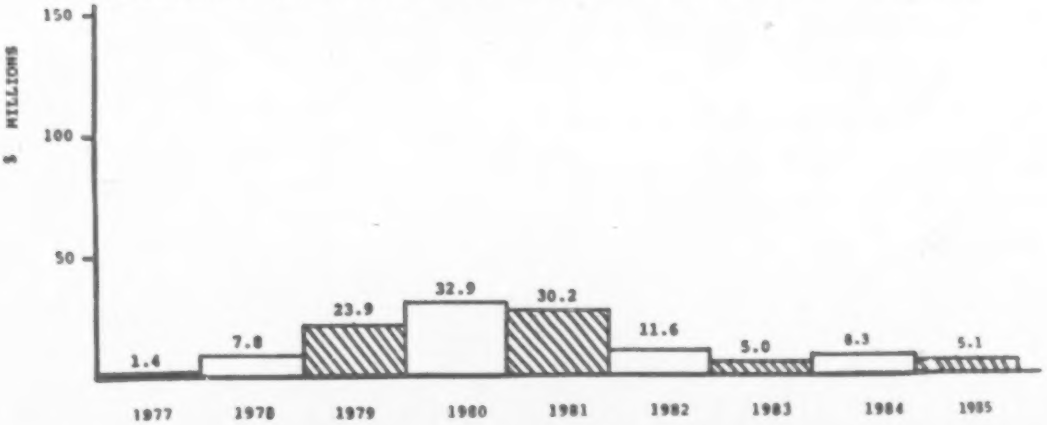
Program	FY84	FY85
Material Research and Development	2.97	1.77
Systems Research and Development	3.94	2.70
Technology Transfer	0.70	0.18
Program Support	0.64	0.37
Capital Equipment*	0.00	0.10
TOTAL	8.25	5.12

* Part of either Material Research and Development or Systems Research and Development in FY84.

Source: FY85 Annual Operating Plan for the Office of Solar Heat Technologies, March 1985.

FIGURE 7-2

U.S. DEPARTMENT OF ENERGY PASSIVE SOLAR RESEARCH AND DEVELOPMENT FUNDING, FY 1977 - FY 1985



There are no federal government tax credits for passive solar designs. However, 39 states offer various incentives for buildings that employ passive solar designs (see APPENDIX I).

INDUSTRY STATUS

It is difficult to define the passive solar industry. The "industry" includes architects, designers and builders who incorporate passive solar techniques in varying ways. It also includes component and material suppliers whose primary business, in some instances, is not related to passive solar. These include glass and masonry manufacturers, and those who produce water storage containers, phase change modules, greenhouse kits, and window insulation.(1)

Only 0.15% of gross revenues are spent on research and development by the building industry, as compared to 4.7% by the automobile industry.(15) Much of current research and development is undertaken by trade associations, state government agencies, and the U.S. Department of Energy.(1)

MARKET STATUS

It is estimated that over 200,000 homes and 15,000 nonresidential buildings employed passive solar designs in the U.S. by the end of 1984.(1)(15) Of the residential homes, almost all are detached, single family units, although markets are apparently developing in attached townhouses and multi-family units.

Revenue estimates for passive solar designers and suppliers are difficult to estimate. There are differences of opinion on what constitutes passive solar as opposed to other construction, and it is difficult to isolate the passive solar component of sales by suppliers such as glass and masonry companies.(1) For a small but growing part of the industry, the greenhouse/attached sunspace market, revenue sales are estimated to be between $50 million and $300 million annually.(1)

In the past, passive solar has appealed primarily to high-income, well-educated consumers who are interested in the social as well as economic benefits of passive solar. There are signs that this pattern is changing, however. Buyers of passive solar designs are now appearing in all income brackets, and passive solar homes in certain regions are beginning to attract first-time home buyers, traditionally a fiscally conservative group. For example, 20% of all first-time home buyers in Richmond, Virginia are buying passive solar homes, and similar trends are being noted in Santa Fe, New Mexico; Boulder, Colorado, and Raleigh, North Carolina.(1)

Most builders, lenders, and real estate agents have not promoted passive solar in new homes and commercial buildings; 40-50% of the largest builders in the U.S. do not include any passive solar designs in their construction.(12) A 1984 survey revealed the following perceptions of passive solar by commercial developers: 1) building projects with passive solar designs will cost more; 2) cash flow or return on investment would decrease on projects with passive solar systems, especially in the long term; 3) the impact of a passive solar design on the project's resale value is uncertain; and 4) the attitudes of the buildings' tenants towards passive solar is unclear.(14)

As a consequence, builders tend to favor "add-on" features with proven selling points like racquetball courts and fountains. Even in this regard, developers have tended to be more willing to make expenditures on conservation equipment (e.g. electric heat pumps, added insulation, double pane windows) than on passive solar systems because they are familiar with it and can include it without significantly changing the design of the building.(14)

When passive solar is used by builders, they tend to favor the simplest and easiest design, such as suntempering or direct gain. This conservatism on the part of builders does not bode well for Trombe walls, phase change materials or new glazing materials because they are considered too complex, risky, and not cost-effective by builders.(18)

Passive cooling may find a market in warm climates, such as Florida or any of the southern states, where 51% of new homes are built.(18) Market perception may pose an obstacle, though. Consumers are unlikely to believe that their need for air conditioners and other cooling equipment can be reduced simply by adding low emissivity materials to the roof and improving ventilation flows.(18)

Another potential market for passive solar lies in the manufactured housing market which accounted for over 25% of all new housing built in the U.S. in 1983 (about 550,000 units).(35) Two modular prototypes using passive solar have been built in Richmond, Virginia. The 1,000 ft^2 (92.9 m^2) model uses direct gain and would sell for $35,000-$40,000, while a 1,500 ft^2 (139.35 m^2) model would sell for $55,000-$60,000. There have been concerns over possible overheating, which but these prototypes avoided by using masonry as thermal storage and minimizing the size and number of windows on the homes. Other than roof-drainage problems, which were corrected, the prototypes have worked well.(21)

PASSIVE SOLAR DESIGN

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Chapter 8

PHOTOVOLTAICS

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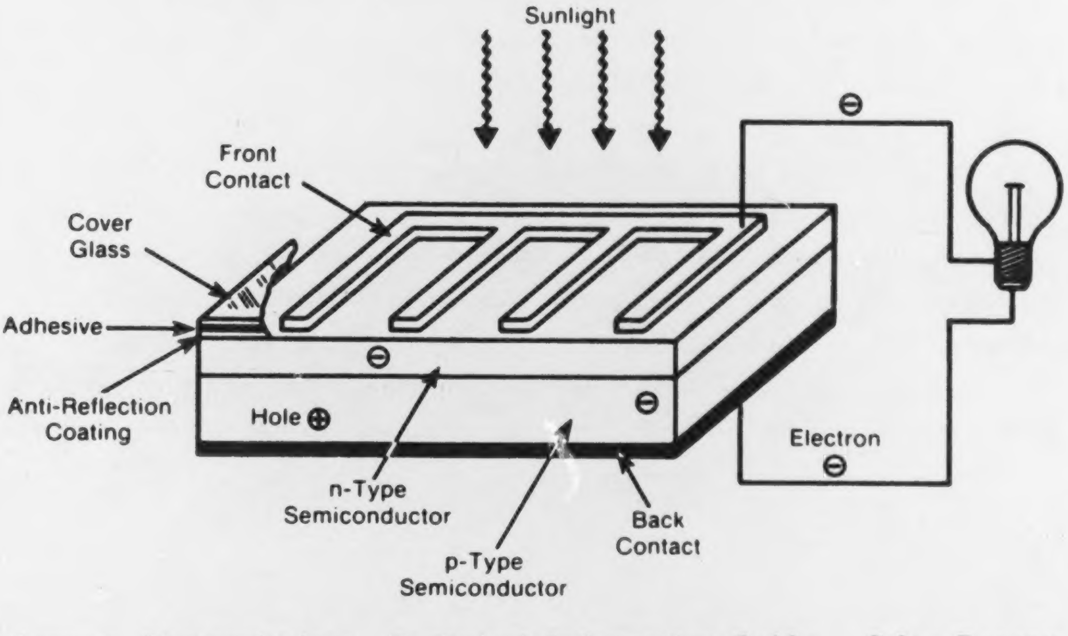
PHOTOVOLTAICS

TECHNOLOGY DESCRIPTION

Photovoltaic (PV) energy systems generate electricity directly from solar radiation. The basic element is the *photovoltaic cell*, also referred to as the *solar cell*. It consists of semiconductor materials that are specially treated to give one layer (the n-layer), a negative charge and the other layer (the p-layer) a positive charge when sunlight enters the cell structure. This sets up a cell barrier (also called the depletion zone, cell junction, or space charge) between the semiconductor materials, creating a current and a voltage across the cell. Sunlight striking the cell excites electrons, which move across the cell barrier. The electron flow is collected by metallic contacts placed on the cell in grid-like fashion (see FIGURE 8-1).(23)

FIGURE 8-1
HOW A PHOTOVOLTAIC CELL GENERATES ELECTRICITY


Sunlight
Front Contact
Cover Glass
Adhesive
Anti-Reflection Coating
Hole ⊕
⊖
⊖
⊖
Electron ⊖
n-Type Semiconductor
p-Type Semiconductor
Back Contact

Source: Photovoltaics: Technical Information Guide. Solar Energy Research Institute, U.S. Department of Energy (SERI/SP-271-2452), February 1985, p. 2.

PHOTOVOLTAICS

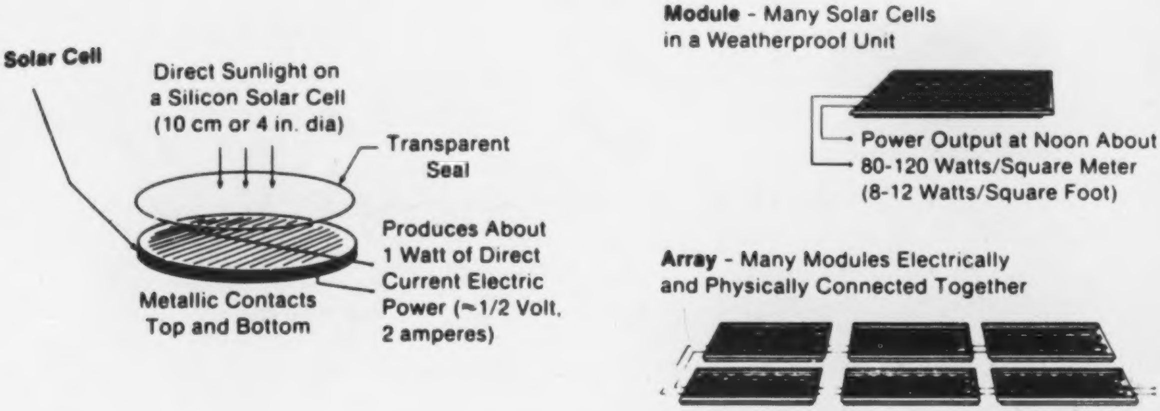
Many materials can be used as semiconductors for photovoltaic cells, the most promising being silicon, gallium arsenide, cadmium telluride, and copper indium diselenide. Several methods exist for using these materials to make photovoltaic cells. The most prevalent is by growing single crystal ingot or casting polycrystalline blocks, which are sliced into thin wafers. New methods form a long, thin ribbon or deposit a thin film onto a substrate. Although photovoltaic cells come in several sizes and shapes, a typical cell is a four inch (10.16 centimeters) square or circle which produces one peak watt (Wp) of direct current electricity. A peak watt is defined as the power generated on a clear day when the sun's rays strikes the cell at a 90° angle.(19)

PV cells are electrically and physically linked together into *modules*. With supporting elements, the entire structure is called an *array* (see FIGURE 8-2).(14) The supporting equipment, referred to as the balance of system, usually consists of support structures, field wiring, control equipment, power conditioning units to convert the direct current (DC) power generated by photovoltaics to alternating current (AC) power for conventional electrical equipment and utility interconnection, and, if necessary, energy storage equipment, the most common being batteries.(15) Some photovoltaic systems use sun tracking systems to increase the amount of direct solar radiation that strike the cells.(14)

Electricity can be produced by two types of modules. With *flat-plate modules*, the total surface area of the cells is about equal to the total area of sunlight striking the module (see FIGURE 8-2). *Concentrator modules* increase the incident sunlight through the use of lenses or mirrors to focus sunlight onto a smaller area of cells (see FIGURE 8-3). This can be accomplished through the use of concentrating lenses over each cell or by placing reflecting panes on the sides of the flat-plate module.

FIGURE 8-2

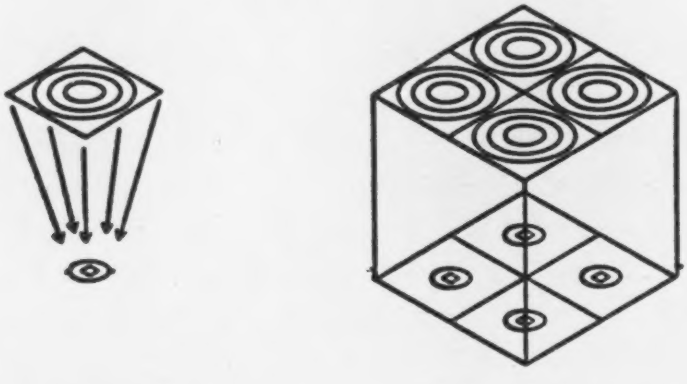
THE PHOTOVOLTAIC CELL, MODULE, AND ARRAY


Solar Cell
Direct Sunlight on a Silicon Solar Cell (10 cm or 4 in. dia)
Transparent Seal
Produces About 1 Watt of Direct Current Electric Power (≈1/2 Volt, 2 amperes)
Metallic Contacts Top and Bottom
Module - Many Solar Cells in a Weatherproof Unit
Power Output at Noon About 80-120 Watts/Square Meter (8-12 Watts/Square Foot)
Array - Many Modules Electrically and Physically Connected Together

Source: Photovoltaics: Technical Information Guide. Solar Energy Research Institute, U.S. Department of Energy (SERI/SP-271-2452), p. 3.

FIGURE 8-3

CONCENTRATOR CELLS AND MODULES



Concentrator Cell

Concentrator Module

Source: Taylor Moore. "Pioneering the Solid-State Power Plant," EPRI Journal, Vol. 10, No. 10, December 1985, p. 8.

APPLICATIONS

PV systems are very versatile with applications in several different power capacities, from a minute fraction of a watt to more than a million watts (megawatt). Five applications have been identified:

- *Specialty* (0.1 watt-1 watt) - consumer products such as watches, calculators, and portable appliances.
- *Space* (15 watts-20,000 watts) - systems that supply the supplementary or primary power needs of satellites and space missions.
- *Stand-alone* (100 watts-200,000 watts) - power systems for private residences, commercial establishments and small towns or villages that are not connected to an electrical power grid. Some common off-grid applications include irrigation, desalination, refrigeration, communication and signaling devices, cathodic protection, water pumping, street lamps and sign lighting, ocean buoy flashers, weather-sensing devices, and field telephones.
- *Grid-Connected Residences* (1-10 kilowatts) - single and multiple family residences that supplement grid-connected electricity or sell excess power to a utility.
- *Grid-Connected Intermediate* (10-300 kilowatts) - systems designed to provide the supplementary or primary electrical needs of commercial, industrial, or institutional facilities, with excess power being sold to a utility.
- *Large central station* (300 kilowatts-1 megawatt or greater) - electric utility-scale systems with output fed directly into the utility grid.

TECHNOLOGY STATUS

Electricity that is produced when light strikes certain materials is called the "photovoltaic effect." It was discovered by French scientist Edmund Becquerel in 1839, with the theory developed by several physicists, including Albert Einstein. Further research was conducted by Bell Laboratory scientists in 1954, who were the first to use silicon for photovoltaic cells. Although the cells eventually reached efficiency levels of 11%, the cost of the power generated was exceedingly high, approximately $600/kWp (kWp).(3) However, photovoltaic cells became recognized as an ideal power supply for satellite applications, due to their light weight and durability. They were first installed on the Vanguard in 1958, the second United States satellite put into space, to supply power to the five megawatt back-up transmitter. The space program of the 1950s and 1960s created a small but steady demand of approximately 80 kilowatts a year. This brought reductions in cost to between $100-200/Wp, still fifty times the cost of grid-connected conventional energy. Higher oil prices in the 1970s caused the governments of the United States, Japan, and several European countries to fund research and development of photovoltaics in an attempt to make photovoltaic systems more economical (see GOVERNMENT SUPPORT). As a result of these efforts, the cost of installing photovoltaic systems has dropped to $8-10/Wp. This has been accompanied by additional gains in efficiencies and durability of cells, modules and systems. These improvements are expected to continue into the next decade (see TABLE 8-1).

TABLE 8-1

GAINS IN PHOTOVOLTAIC SYSTEM AVERAGE PERFORMANCE

	1973	1983/84	1990's (Goals)
System Efficiency	4%	9%	13%-25%
System Lifetime	3 YRS	20 YRS	30 YRS
System Cost	$5000/m^2	$1000/m^2	$125/m^2
Electricity Cost	$15.00/kWh	$0.75-$1.25/kWh	$0.06/kWh
Installed Costs	n.a.	$8-10/Wp*	$1/Wp**

Note: kWh=Kilowatt Hour
Wp=Peak Watt

* $/peak watt. 1983-84 figure provided by Andrew Krantz, U.S. Department of Energy, January 23, 1986.

** "U.S. PV Market Forecast at $2 Billion by Year 2000 in Frost & Sullivan Report," Solar Energy Intelligence Report, Vol. 11, No. 33, August 19, 1985, p. 284.

Source: Robert H. Annan. Photovoltaics: Energy, Business & Science Opportunities. Washington, D.C.: U.S. Department of Energy, Photovoltaic Energy Technology Division, p. 10-2, 1983.

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Semiconductor Materials and Methods of Cell Production

Single crystal silicon has been the predominant semiconductor material used in PV cell production since 1980. However, its market share has steadily declined, from 91% in 1980 to 44% in 1984. Amorphous silicon and semi-crystalline are the next most commonly used semiconductor materials, accounting for 25% and 17%, respectively, in 1984.(1)

One of the causes of the declining market share of single crystal silicon is the inherent limitations of the cell manufacturing method, known as the *Czochralski process*. Consequently, industry efforts have been targeted at developing new materials and production processes. Silicon, purified to the point of having only one non-silicon atom per billion, is melted at a high temperature and then slowly drawn from a crucible, resulting in a large, cylindrical crystal ingot. The crystal is then sliced into thin wafers, typically 1/100 of an inch thick. About half of the silicon becomes useless silicon dust during the cutting process. This complex and time-consuming process adds considerably to the cost of producing silicon cells. Consequently, research and development efforts are focusing on other production methods and semiconductor materials as a means of reducing costs. Two of these production methods are thin films and ribbon growth.

- *Thin films* are typically only a few thousandths of an inch thick and are made by directly depositing a semiconductor material on a substrate by techniques such as glow discharge, chemical vapor depositation and electrochemical depositation. A major advantage of thin films is that they require no cutting of the semiconductor material. Several semiconductor materials are being investigated for use as thin films, including amorphous silicon, polycrystalline silicon, copper indium diselenide and gallium arsenide.(19)(29)

- The *ribbon process*, including *edge-defined film-fed growth (EFG)*, *ribbon-to-ribbon*, and *dendritic web*, occurs by inserting and then withdrawing a seed crystal of a semiconductor material from a molten pool of the parent semiconductor material. Researchers are attempting to increase the speed at which ribbons are pulled while maintaining good quality.(29)

Other materials have shown they would make effective semiconductors for photovoltaic cells, including copper indium diselenide, cadmium telluride, and gallium arsenide.(4)(19)(23) Some of these materials are being investigated as possible components of *tandem* or *multijunction* cells, which combine two or more photovoltaic cells in an effort to capture a wider range of the solar spectrum.(19) Research is underway on combining gallium arsenide with either single crystal or amorphous silicon, and cadmium sulphide with copper indium diselenide.(4)

1984 proved to be a remarkable year for progress in the development of photovoltaics. Notable accomplishments occurred in single crystalline silicon, polycrystalline silicon, dendritic web, gallium arsenide and amorphous silicon (see TABLE 8-2). Three firms began producing amorphous silicon modules in 1984, and commercial production of thin film cadmium telluride and gallium arsenide was scheduled to begin in 1985.(4)

TABLE 8-2

PROGRESS IN PHOTOVOLTAIC CELL EFFICIENCY, 1982-84

(Laboratory Cells)

	1982	1983	1984
Single Crystalline Silicon	12%	16%	19%
Polycrystalline Silicon	10.5%	14%	14.5%
Silicon Ribbon (EFG)	12%	12%	14%
Amorphous Silicon	5%	7%	12%
Gallium Arsenide	15-17%	23%	24%
Copper Indium Diselenide	10%	11%	12%
Dendritic Web	14%	15%	16%

Sources: Jeffry Erickson and Carlo La Porta. Energy Innovation: Development and Status of the Renewable Energy Industries. Washington, D.C.: Solar Energy Industries Association, pp. B1-B11.

Personal Communication, Andrew Krantz (U.S. Department of Energy, Washington, D.C.), January 23, 1986.

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Consumer Product and Stand-Alone Systems

Photovoltaic systems are now more reliable and economical than many other energy technologies for many stand-alone and consumer product applications. An excellent example is the cells that power consumer electronic products such as hand-held calculators. Nine cells, each 1/4 inch by 1/2 inch (0.6 cm by 1.3 cm) power a calculator, with the whole array being 1/2 inch by 2 inches (1.3 cm by 5 cm). The system produces a few thousandths of a watt at 3-4 volts. The system has no storage and operates only when light strikes the photovoltaic cells, eliminating the need for batteries and an on-off switch. These calculators retail for less than $20.

Photovoltaic cells can also provide power to light signs and billboards. These systems usually consist of one-to-two modules that produce less than 100 watts at peak operation. Hikers, campers, and backpackers can now use portable photovoltaic systems containing 10 watt panels wrapped in a 6 inch by 12 inch (15 centimeter by 30 centimeter) pouch.(23)

Larger systems are providing power for homes and businesses located in remote areas in the U.S. In these areas, connecting to the nearest utility distribution system may be prohibitive in cost.(23) A photovoltaic system can be used to power lights, a radio, television and other small appliances. These remote systems consist of between 5 and 20 modules, depending on how much power is needed and whether a back-up power system is available.(23)

Utility Systems

Current efforts to decrease cell costs and increase cell efficiency will have an impact on the development of flat plate and concentrator modules for utility grid-connected photovoltaic systems. Additional improvements in reducing balance of system costs and increasing overall system performance are expected as a result of the experience from several central station photovoltaic systems in the U.S.

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Flat plate modules currently are not economical for utility applications because of low energy efficiencies (8-14%) and high costs, estimated to be in excess of $\$45/ft^2$ ($\$500/m^2$).(14) The Electric Power Research Institute (EPRI) estimates that for flat plate modules to be competitive with conventional energy technologies for utility applications by the 1990s, they must achieve 15% or better efficiencies, cost no more than $\$14/ft^2$ ($\$150/m^2$) and have a lifetime of 20-30 years.(2)

Concentrator modules use lenses or reflectors that focus direct sunlight onto solar cells (usually single crystal silicon) to increase cell efficiency, thus reducing the amount of cell area required by as much as 1/1000th of that of a flat plate module. As a consequence, the cost of the solar cells can amount to as little as 5% of the overall cost of the concentrator system.(29) Concentrators generally do not perform well under diffuse or indirect sunlight, though, which geographically limits concentrators to clear, dry areas such as the southwestern United States. Concentrators also require tracking systems, maximizing energy production but adding more moving parts and thereby increasing system complexity.(19) EPRI estimates that for concentrator modules to become competitive with conventional energy sources for utility applications by the 1990s, they must achieve energy efficiencies of 22% or more and costs not exceeding $\$24/ft^2$ ($\$250/m^2$).(2) Two commercial suppliers have produced concentrator modules that exceed this cost goal at $\$12/ft^2$ ($\$125/m^2$). However, at 15% efficiencies, they are still short of meeting the 1990s system efficiency goal.(29)

Balance of system costs for support and power conditioning equipment can account for approximately 30% of overall system cost.(13) Research and development is concentrating on reducing support system costs by one-third to one-half and increasing the efficiency of power-conditioning units.(29)

Overall system performance data for central station PV plants is somewhat limited, being extrapolated from only a few installations. However, the following trends can be noted:

- *Availability* for currently installed photovoltaic systems used for power production ranges from 80-90%. With improvements, availabilities should exceed 90%.(14)

- *Capacity factors* vary between 8% and 20%, depending on the type of module, what semiconductor material is used, and where the system is located.(14)

- *Operating and maintenance* (O&M) costs for current photovoltaic plants range between 0.4¢/kWh and 2.8¢/kWh. By the 1990s, all central station photovoltaic systems are expected to incur O&M costs of less than 1¢/kWh.(14)

- *Module lifetime*, until recently, has usually been less than 10 years, but recent advances have encouraged some manufacturers to offer 10 year warranties. By the 1990s, it is hoped module lifetimes will be 30 years or more.(29)

GOVERNMENT SUPPORT

Federal research and development support for photovoltaics comes from the Photovoltaic Systems branch of the Office of Conservation and Renewable Energy, U.S. Department of Energy. For Fiscal Year 1985, the research and development budget was $56.61 million, a 12% increase from Fiscal Year 1984 (see TABLE 8-3 and FIGURE 8-4).

TABLE 8-3

U.S. DEPARTMENT OF ENERGY FUNDING FOR PHOTOVOLTAICS RESEARCH AND DEVELOPMENT, BY PROGRAM
($ millions)

	FY83	FY84	FY85
Materials Research	25.88	26.0	30.61
Collector Research	10.15	9.3	10.50
Systems Research	15.09	13.6	5.00
SMUD	6.80	1.5	9.50*
Capital Equipment	-----	----	1.00
Total	57.92	50.4	56.61

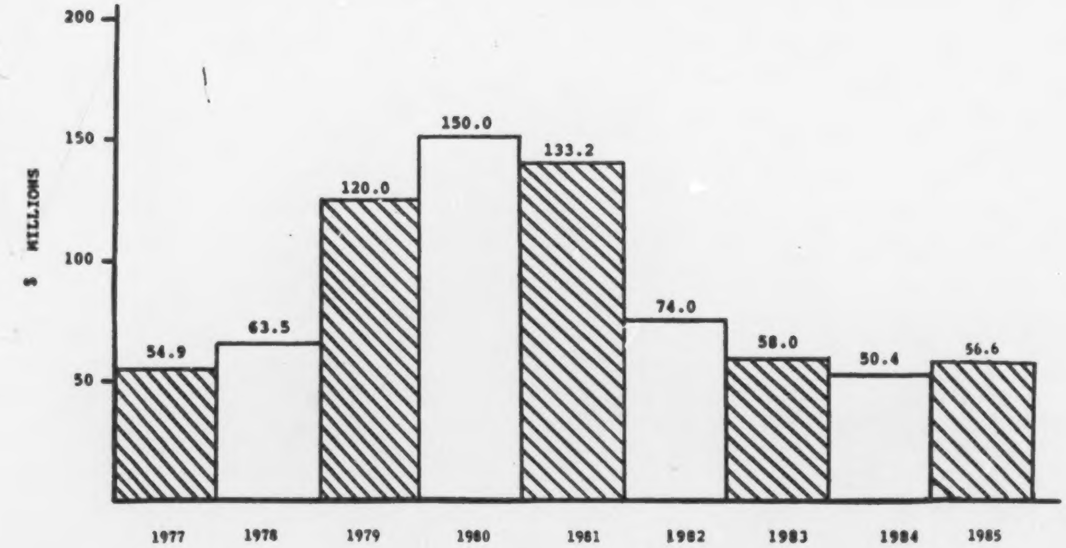
* Sacramento Municipal Utility District (SMUD) was discontinued in 1985. Funds are scheduled for redistribution to other photovoltaic programs.

Sources: Renewable Technologies Program Summaries. Deputy Assistant Secretary for Renewable Energy, U.S. Department of Energy (DOE/CE-0105), November 1984, p. 28.

U.S. Department of Energy FY86 Congressional Budget Request: Energy Supply Research and Development--Solar and other Renewables. U.S. Department of Energy, Vol. 2, p. 45.

FIGURE 8-4

U.S. DEPARTMENT OF ENERGY PHOTOVOLTAIC RESEARCH AND DEVELOPMENT FUNDING, FY 1977 - FY 1985



The Public Utilities Regulatory Policy Act (PURPA) requires utilities to buy power from small independent power producers at the utilities' avoided cost rates. Small photovoltaic power plants (under 80 MW) qualify under PURPA regulations.

A 15% federal business energy tax credit for investments in photovoltaic energy systems, and a 40% residential energy tax credit (limited to $4,000, or 40% of a $10,000 investment) expired at the end of 1985. Forty-four states offer various incentives for the installation and development of photovoltaic systems (see APPENDIX I).

Other countries besides the U.S. have active research and development programs in photovoltaic systems, most notably in Europe and Japan. Several countries in Europe, in addition to their own national photovoltaic programs, participate in programs offered by the Commission of European Communities (CEC). The CEC has participated in 13 photovoltaic projects facilities, with 2 more being planned. Japan, through the "Sunshine Project," increased government support from less than $10 million in 1980 to over $30 million in 1984.(1)(19)

INDUSTRY STATUS

Twenty-three companies manufactured modules in the U.S. in 1984, as compared to 16 in 1980, while 40 to 60 companies are involved in sales and/or research.(28)(16) In all, $85 million was spent on research and development by private enterprise in the United States in 1984.(17) Revenue from the sale of photovoltaic modules and cells dipped slightly in the U.S. in 1984 to $127.6 million, as compared $128.7 million in 1983.(16)

U.S. photovoltaic industry involvement ranges from divisions of major corporations, especially oil companies, to several small, start-up businesses. Four of the top seven photovoltaic firms in cell production in 1983 were owned by major oil companies.(3) One oil company left the photovoltaic industry in 1984, while two other large non-oil corporations purchased or became active with other photovoltaic firms.(4)

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Twelve companies produced modules in Europe in 1984. The photovoltaic industry in Europe has been dominated by major electronic companies. European photovoltaic firms rely heavily on government-funded research and development and demonstration projects (see GOVERNMENT SUPPORT).(1)

Fourteen companies produced modules in Japan in 1984. Similar to Europe, the electronics industry is very involved in photovoltaics. Most companies produce amorphous silicon for small electronic products like calculators and watches, but some are beginning to produce modules for larger applications.

Worldwide photovoltaic production in 1984 was at between 50-60% of potential capacity. Manufacturers could potentially produce between 40-45 megawatts annually, according to one estimate.(17) Revenues for photovoltaic module manufacturers worldwide increased from $200 million in 1983 to $250 million in 1984. For the complete PV industry, revenues increased to $394 million in 1984 from $365 million in 1983.(1)

MARKET STATUS

Overall, world photovoltaic shipments increased in 1984, although sources differ over the amount of increase (see TABLE 8-4). The U.S. market share in world photovoltaic production, once nearly unchallenged, slipped in 1984 due to a fall-off in central utility applications. At the same time, Japan's market share rose because of the continued popularity of small consumer goods like calculators and watches.

TABLE 8-4

ESTIMATES OF WORLD ANNUAL PHOTOVOLTAIC SHIPMENTS AND MARKET SHARE

	Megawatts Shipped						Market Share	
	1980	1981	1982	1983	1984	1983-84 Change	1983	1984
U.S.	2.5	3.5	4.9	12.5	11.6	-7%	58%	50%
Japan	0.5	1.1	1.7	5.3	7.7	+45%	25%	33%
Europe	0.4	0.9	1.7	3.3	3.3	0%	15%	14%
Other	0.1	0.1	0.1	0.4	0.6	+33%	2%	3%
World	3.4	5.5	8.4	21.5	23.2	+8%	---	---

Source: J.A. Dirks, S.A. Smith, and R.L. Watts. Photovoltaic Industry Progress Through 1984 (DE-AC06-76RLO-1830). Richland, WA: Batelle Memorial Institute, Pacific Northwest Laboratory, April 1985, p. 2.1.

	Megawatts Shipped		Market Share	
	1983	1984	1983	1984
U.S.	9.3-13.1	8.5-15.0	60%	46-54%
Japan	3.8- 5.0	6.6- 8.9	21-24%	28-36%
Europe	2.2- 3.5	2.6- 4.0	14-17%	14%
Other*	0.3- 0.5	0.8- 1.0	1-2%	3-4%
World	15.6-22.1	18.5-28.9	------	------

* "Other" is essentially two photovoltaic manufacturers in India and Brazil.(1)

Sources: Photovoltaics Insider's Report, PV News, and Strategies Unlimited.

A close examination of the photovoltaic market by end-use reveals why U.S. market share has declined while Japan's has increased. In 1983, the central station and grid intermediate markets accounted for 68% of U.S. PV shipments; this decreased to 44% in 1984.(4) The future of this market in the U.S. is likely to depend on improvements in cell efficiencies and system economics, as well as utility needs for additional power capacity and the competing cost of conventional energy sources. For the immediate future, this particular market is generally considered to be stagnant.(4)

In contrast, the world market for specialty markets increased in 1984 (see TABLE 8-5). Over 150 million calculators using photovoltaics have been sold world-wide, accounting for 60% of the calculator market. Photovoltaic calculator sales have now reached sales of 60-70 million annually. Japan developed this market in 1981 and has dominated it ever since.(4) In 1984, this market accounted for 86% of Japan's photovoltaics shipments.(1) The increasing market has stimulated a large demand for small, individual photovoltaic cells for specialty markets, fetching up to $50 a watt.(4)

TABLE 8-5

WORLD SHIPMENTS TO END-USE MARKET SECTORS

(Capacity and Market Share)

	1981		1982		1983		1984	
	(MWe)	(%)	(MWe)	(%)	(MWe)	(%)	(MWe)	(%)
Specialty	0.8	17	1.2	15	4.1	19	6.2	27
Stand-Alone	3.6	76	3.9	52	7.7	36	10.7	46
Grid Residential	0.1	1	0.1	2	<.1	1	<.1	1
Grid Intermediate	0.3	6	0.5	7	1.0	5	0.6	3
Central Station	0.0	--	1.8	24	8.7	40	5.7	24
TOTAL	4.8	100	7.5	100	21.5	100*	23.2	100*

* Total exceeds 100% due to rounding.

Source: J.A. Dirks, S.A. Smith, and R.L. Watts. Photovoltaic Industry Progress Through 1984. Richland, WA: Batelle Memorial Institute, Pacific Northwest Laboratory, April 1985, pp. 4.5 and 4.6.

The market share of stand-alone applications increased world-wide, from 36% in 1983 to 46% in 1984, regaining earlier dominance over the other end-use markets (see TABLE 8-5). In the U.S., installed capacity in this sector rose from 0.8 megawatts in 1983 to 1.5 megawatts in 1984. Further gains are projected, since stand-alone systems are cost-effective over other small power sources in remote areas.(1) It is estimated that between 5,000-10,000 remote photovoltaic systems rated 1 kilowatt or less are sold in the U.S. each year. Some homes and communities across the U.S. have turned to photovoltaics as a power source, due to the prohibitive high cost of connecting to a central utility. For example, fifty percent of the homes on Monhegan Island, Maine are supplied power by photovoltaic systems.(23)

By customer market sector, the trend is towards consumer applications (a 56% increase in 1984) and away from industrial installations (down 43% in 1984). Another area of growth is in the commercial sector, which witnessed a 71% increase in photovoltaic shipments in 1984 (see TABLE 8-6). Activity in this sector may be due to the rise in the number of photovoltaic distributors and retailers who sell complete systems.(1)

TABLE 8-6

WORLD SHIPMENTS TO CUSTOMER MARKET SECTORS

(Megawatts/year)

	1981	1982	1983	1984
Residential	1.0	1.0	1.8	2.1
Commercial	1.4	2.7	3.8	6.5
Agricultural	0.2	0.4	0.7	0.6
Industrial	0.2	1.2	8.7	5.0
Government	1.2	1.0	2.5	2.7
Consumer	0.8	1.2	4.0	6.3
Total	4.8	7.5	21.5	23.2

Source: J.A. Dirks, S.A. Smith, and R.L. Watts. Photovoltaic Industry Progress Through 1984. Richland, WA: Batelle Memorial Institute, Pacific Northwest Laboratory, April 1985, p. 2.1.

Exports to developing countries represent a promising market. In 1984, 22% of U.S. sales were due to exports, up from 15% in 1983.(28) A high potential market for photovoltaics lies in remote areas overseas where access to electricity is restricted. The United Nations has estimated that over 2 million villages worldwide do not have electricity. To help stimulate this market, U.S. government agencies, including the Agency for International Development, have sponsored photovoltaic demonstration projects in Tunisia, Morocco, Nepal, Upper Volta, Saudia Arabia, and many other countries.(23) By 1991, it is estimated that 46 megawatts of photovoltaics will be located in remote areas, as compared to 4 megawatts in 1983.(24) Potentially, this market could account for 316 megawatts of photovoltaic capacity a year.(23)

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Chapter 9

SOLAR HEATING AND COOLING

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SOLAR HEATING AND COOLING

TECHNOLOGY DESCRIPTION

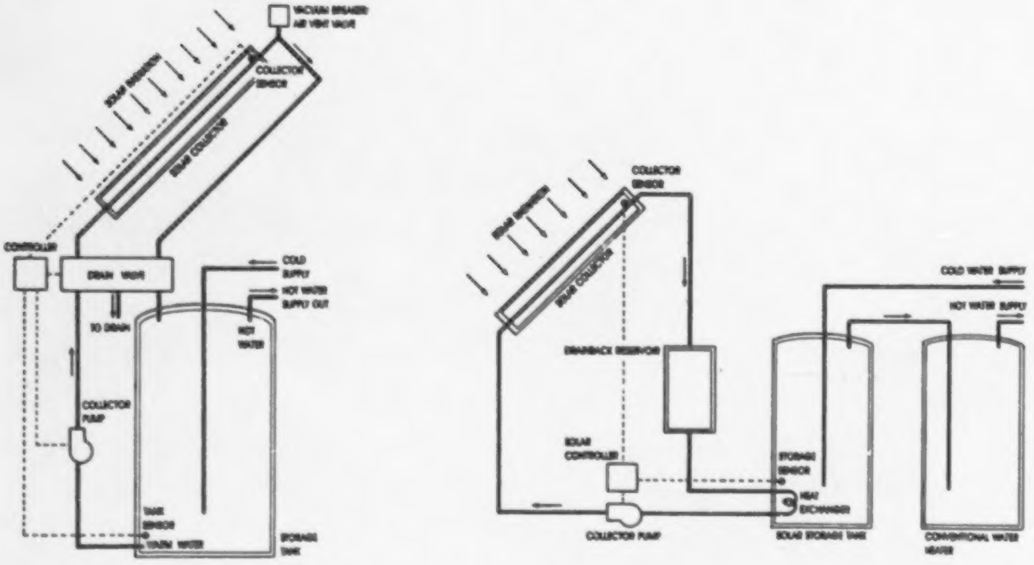
Solar heating and cooling is characterized by the use of solar collectors to convert the sun's energy to useful heat for domestic water heating, space conditioning, pool heating, and industrial process heating. Collectors are usually insulated metal boxes with glass covers that contain a black absorber plate. Air or liquid is heated as it circulates across the absorber plate. The hot air or liquid is then transported to storage or directly to an end-use. Because mechanical energy is often required to move the working fluid, these systems are referred to as "active" solar. An exception are passive water heaters.

In *active* systems, a small pump or fan forces the liquid or air through the collector and to the storage tank. Active systems can be divided into air or liquid systems. There are two types of liquid-based systems: open-loop and closed loop. In open-loop systems, the circulating liquid is potable water, which is used directly. Open-loop systems can be protected from freezing by the use of draindown devices, which empty the water from the collector when outdoor temperatures drop below a certain point. Closed-loop systems, on the other hand, prevent freezing by employing drainback devices that empty the collector water into a feeder tank, or an anti-freeze liquid that is circulated through the collector and then passed through a heat exchanger to heat the potable water (see FIGURE 9-1). In mild climates, either system can use recirculation from storage to prevent freezing of the collectors.

Air-based systems are similar to liquid-based systems, except a fan replaces the pump to force circulation. The hot air can be used directly for space heating or coupled with a storage unit which stores the heat for later use. Storage units usually contain rocks for space heating, or water for domestic hot water applications (see FIGURE 9-1).

FIGURE 9-1

DRAINDOWN AND DRAINBACK SYSTEMS

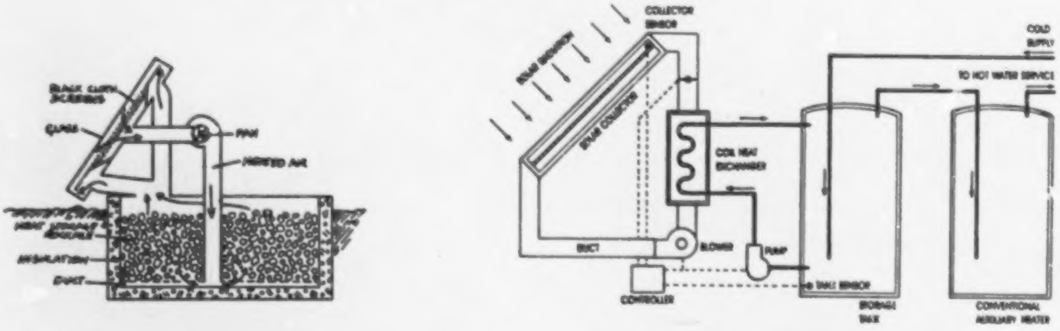

VACUUM BREAKER/ AIR VENT VALVE
COLLECTOR SENSOR
SOLAR RADIATION
SOLAR COLLECTOR
CONTROLLER
DRAIN VALVE
COLD SUPPLY
HOT WATER SUPPLY OUT
TO DRAIN
HOT WATER
COLLECTOR PUMP
TANK SENSOR
WARM WATER
STORAGE TANK
COLLECTOR SENSOR
SOLAR RADIATION
SOLAR COLLECTOR
COLD WATER SUPPLY
HOT WATER SUPPLY
DRAINBACK RESERVOIR
SOLAR CONTROLLER
STORAGE SENSOR
HEAT EXCHANGER
COLLECTOR PUMP
SOLAR STORAGE TANK
CONVENTIONAL WATER HEATER

Draindown System**

Drainback System**

FIGURE 9-2

INDIRECT AND DIRECT AIR COLLECTORS


BLACK CLOTH SCREENS
GLASS
FAN
HEATED AIR
HEAT STORAGE
INSULATION
DUCT
COLLECTOR SENSOR
SOLAR RADIATION
SOLAR COLLECTOR
COLD SUPPLY
TO HOT WATER SERVICE
COIL HEAT EXCHANGER
DUCT
BLOWER
PUMP
TANK SENSOR
CONTROLLER
STORAGE TANK
CONVENTIONAL AUXILIARY HEATER

Direct Air System*
(with storage)

Indirect Air System**
(without storage)

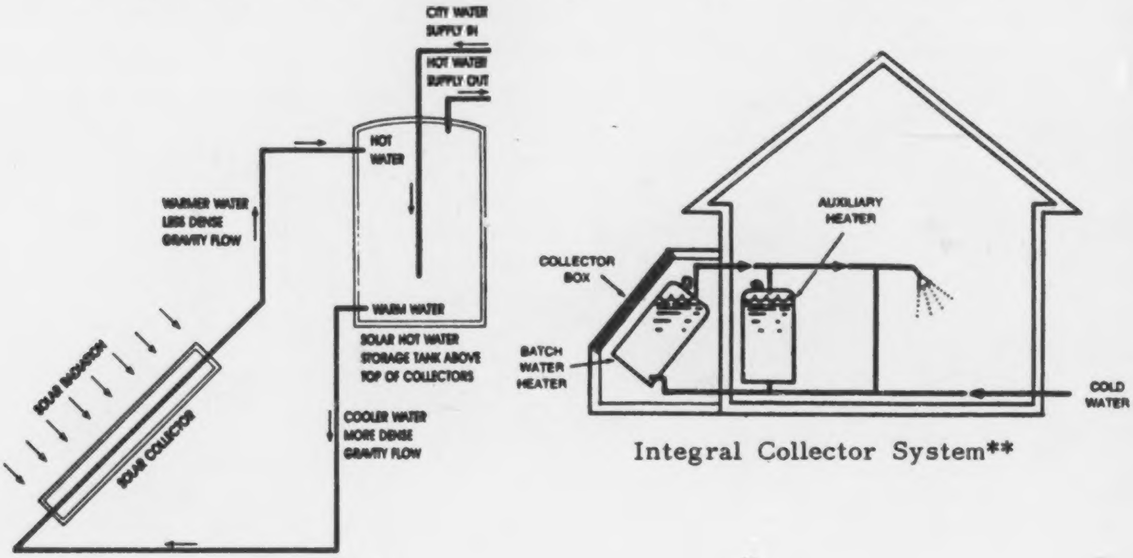
Sources: * Bruce Anderson. The Solar Home Book. Andover, MA: Brick House Publishing Company, 1976, p. 28.

** David Miller and Grant Price. Solar Water Heating: A Guide for New Mexico Homeowners. Las Cruces: New Mexico Solar Energy Institute, pp. 19, 21, and 22.

No pumps are used in *passive* systems. In thermosiphon designs, the storage tank is mounted higher than the collector so the heated liquid rises by convection into the tank and is replaced by cooler water at the bottom of the tank (see FIGURE 9-3). The tank can be separate from the collector and placed inside the building, but most thermosiphon systems are single units with the tank attached to the collector. Integral collector storage systems, sometimes referred to as batch or breadbox designs, use a black-painted tank or series of tanks as both collector and storage. As hot water is drawn off from the top of the tank, cold water enters the bottom and is heated by solar radiation (see FIGURE 9-3).

FIGURE 9-3

THERMOSIPHON AND INTEGRAL COLLECTOR STORAGE SYSTEMS


CITY WATER SUPPLY IN
HOT WATER SUPPLY OUT
HOT WATER
WARMER WATER LESS DENSE GRAVITY FLOW
WARM WATER
SOLAR HOT WATER STORAGE TANK ABOVE TOP OF COLLECTORS
SOLAR RADIATION
SOLAR COLLECTOR
COOLER WATER MORE DENSE GRAVITY FLOW
AUXILIARY HEATER
COLLECTOR BOX
BATCH WATER HEATER
COLD WATER

Integral Collector System**

Thermosiphon System*

Sources: * David Miller and Grant Price. Solar Water Heating: A Guide for New Mexico Homeowners. Las Cruces: New Mexico Solar Energy Institute, p. 17.

** From Passive and Active Solar Domestic Hot Water Systems. Conservation and Renewable Energy Inquiry and Referral Service, U.S. Department of Energy (DOE/CE-0125), June 1985, p. 3.

The heat from solar collectors can also be used to operate an air-conditioning system. Researchers have identified five potential solar cooling systems: absorption cycle systems, vapor jet systems, Rankine cycle systems, closed-cycle adsorption, and open-cycle adsorption systems.(6)

APPLICATIONS

Low temperature (Less than 110°F, or 43°C) solar heating systems, which typically employ unglazed collectors, are used primarily for pool heating. An average home pool uses 300 ft^2 (28 m^2) of collector and a pump to circulate the water. No storage is needed.

Medium-temperature (110-180°F, or 43-82°C) systems have the broadest applications: domestic water and space heating, air conditioning, commercial water and space heating, and industrial process heat. Applications include the following:

- Domestic water heating systems can be active or passive and have an average collector area of 40-60 ft^2 (3.7-5.6 m^2). Passive systems are used almost exclusively for domestic water heating applications.
- Residential space heating systems use 150-300 ft^2 (14-28 m^2) of air or liquid collectors and incorporate enough storage capacity for 1-2 cloudy days. Smaller air systems with no storage have recently become popular.
- Solar cooling systems can be used in residential or commercial buildings. This application is not yet widely commercialized, so it is too early to say what size system will be optimum. The Solar Energy Industries Association (SEIA) estimates a single family solar cooling system would be about 225 ft^2 (21 m^2). A wide range exists for commercial systems, depending on cooling loads, but an average reported by SEIA is 4,000 ft^2 (372 m^2).(8)
- Commercial solar water heating systems are popular in hospitals, restaurants, and laundromats, which have large hot water needs, but they are practical for any building where hot water is needed. System sizes tend to be about 500 ft^2 (46 m^2), according to SEIA.(8)

- Solar space and water heating systems can be utilized for district heating, i.e., meeting the heating or hot water needs of several buildings from a central heat source that supplies steam or hot water through a distribution network. District heating is is more common in Europe than in the U.S.(14)

- Industrial solar water heating systems are still relatively rare in the U.S. They tend to be large, up to 300,000 ft^2 (27,871 m^2). Medium-temperature collectors (110-180°F, or 43-82°C) are sufficient for industrial applications in this temperature range.

High-temperature collectors (180-212°F, or 82-100°C) are used primarily for industrial processes that need hot water for cooking, washing, bleaching, anodizing, and refining. For systems producing heat for higher temperature industrial process heat applications, see *SOLAR THERMAL*.

TECHNOLOGY STATUS

Solar Heating Systems

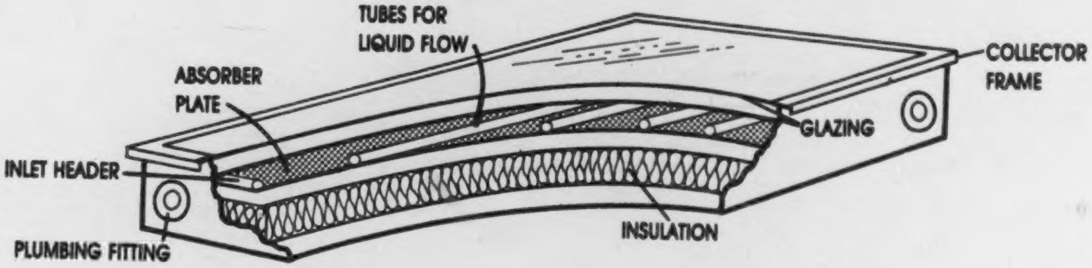
The first *solar water heaters* were available in the United States in 1881. These were simple batch heaters that were not even connected to the regular hot water supply. The design was improved in the early 1900's by connecting the solar system to the conventional water heater and flattening the absorber tank to increase efficiency. The first thermosiphon system was also introduced at this time. The collector had a wood frame, copper absorber, and glass cover. The storage tank was mounted inside the house. In the 1930s, insulation and metal framing were introduced.

The solar water heating market largely disappeared after World War II, when conventional energy was cheap and abundant. Several universities began research into solar space heating using pumped systems during the postwar period. When public interest in solar heating revived in the 1970s, low-temperature systems for pool heating were the first to achieve significant market penetration and were first to use polymers (plastics) in the collector.

Pumped liquid systems quickly became the industry's medium-temperature standard. After experimenting with aluminum absorber plates and tubing, the industry began utilizing copper, due to its resistance to corrosion, its widespread use in domestic plumbing, and its high heat conducting capabilities. Increased competition has led some manufacturers to develop aluminum absorbers in an effort to lower costs; however, copper remains the industry standard, although sometimes in combination with aluminum or steel.(1)(12) Rigid board and/or fiberglass batt insulation is included in current collector designs behind the absorber plate to minimize thermal heat loss. The frame is typically made of extruded aluminum. To maximize solar transmittance, low-iron tempered glass is often used as a glazing material (see FIGURE 9-4). A pump and a controller complete the collection system, with temperature sensors both in the tank and in the collector that are wired to the controller, which works like a thermostat in starting and stopping the pump and, depending on the system type, draining the collector to prevent freezing.

FIGURE 9-4

LIQUID COLLECTOR



Source: David Miller and Grant Price. Solar Water Heating: A Guide for New Mexico Homeowners. Las Cruces: New Mexico Solar Energy Institute, p. 11.

The technology is proving itself practical and reliable, with industry standards and ratings providing essential reassurance to consumers. At $11/ft^2 ($118/m^2) installed, low-temperature pool heating systems are generally considered competitive with conventional systems in warm climates.(1) For medium temperature space and water heating systems, however, price and payback period remain an obstacle (see TABLE 9-1).

TABLE 9-1

ESTIMATES OF AVERAGE SIZES
AND COSTS OF SOLAR HEATING AND COOLING SYSTEMS

(1984 $)

Type	Average Ft^2 of System	Cost Per Ft^2	Total System Cost
Single Family			
Pool	300-400	$11	$ 3,300- 4,400
Hot Water	60	$50-100	$ 3,000- 6,000
Space Heating			
(Liquid)	250	$50- 75	$12,000-19,000
(Air)	40-200	$50	$ 4,000-10,000
Cooling	*	*	*
Commercial/Industrial			
Pool	1,000 - 1,500	$ 5- 50	$ 5,000-75,000
Hot Water	500-300,000	$40-100	$20,000 and up
Cooling	*	*	*
Space Heating	*	*	*

* Systems in early stage of commercial development; consequently, average size and cost information not available.

Derived From: Kevin Finneran, Consultant.
Jeffry J. Erickson. Statistical Analysis of the Solar Energy Industry. Washington, D.C.: Solar Energy Industries Association, July 1985, p. 16.

To reduce costs, government and national laboratory research efforts have concentrated on alternatives to copper and low-iron glass. Several polymers made from fluorocarbons, acrylics, and silicons are being tested as possible absorber and glazing materials, while polybutylene has emerged as a promising piping material, since connections are made by crimped fittings rather than soldering.(14) Because marketing costs often account for a substantial portion of the overall cost of the system to consumers, technical improvements alone may not solve the problem of high system costs.(1)

Another means of reducing costs and improving system reliability is using simpler designs. Passive solar water heating systems use the same materials as active systems, but need no pump or controller. These systems are generally installed where freezing temperatures rarely occur. They can be installed in northern latitudes if appropriate freeze protection devices are included in the design.

Thermosiphon systems are the most common solar domestic hot water systems in the world and are popular in Australia, Japan, China, and the Middle East. The system has no controls or moving parts, resulting in lower start-up costs and high reliability. Two disadvantages of thermosiphon systems are the potential of freezing and the installation of the storage tank.(14)

In a thermosiphon system, water is in the tank at all times. If the water freezes, the pipes or the storage tank may burst.(15) One solution currently in practice in Arizona, California, Florida, Hawaii, and New Mexico is to protect the collector with an electric heating element. This can work well if freezing conditions are uncommon. Other solutions include the installation of a draindown device, an antifreeze/water solution or phase change working fluid and heat exchanger.(15)

Because thermosiphon systems rely on convection to circulate the water, the storage tank must be installed 1-2 feet (0.3-0.6 meters) above the collector. If the collector is installed on the roof, the storage tank must be placed on an upper floor or under the roof ridge, possibly requiring the reinforcement of these areas due to the weight of full water tanks.(15)

Integral collector storage (ICS) heat and store water on the roof. To increase performance, these systems also take advantage of black chrome coating and low-iron tempered glass. ICS systems use double or triple-glazing to reduce heat loss and often include reflectors behind the tank to increase solar gain. Because most of the feed pipes and water storage tanks are outdoors, overnight heat losses may be excessive. To prevent freezing, a few include an electric heating element in the tank.

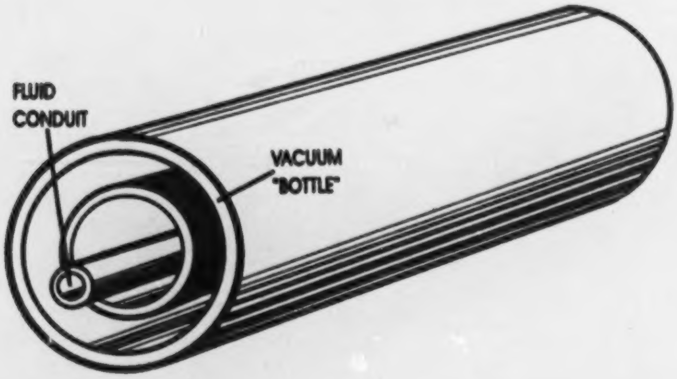
Performance considerations can sometimes outweigh the cost advantages of low-cost collectors such as the ICS. For example, the smaller collector size of the ICS increases the per square foot cost to about equal that of closed-loop systems. The smaller collector also decreases the amount of energy an ICS system delivers.(2)

Collector efficiencies also affect the amount of energy a system can deliver. Two factors that can affect collector efficiency include collector heat losses (the difference between the absorber temperature and the outdoor temperature), and solar insolation, i.e. the amount of solar radiation striking an area, measured usually in watts/m^2/hr or BTUs/ft^2/hr (see RESOURCE AVAILABILITY).

Some manufacturers are pursuing the opposite strategy, improving efficiency rather than reducing costs. One option is the evacuated tube collector in which the liquid is circulated through pipes that are encased in a glass tube. Evacuated tube collectors can cost twice as much as flat plate collectors per square foot, but because they are more efficient, a similar sized evacuated tube system will deliver more energy. A vacuum is created in the space between the exterior glass tube and interior transport tube to reduce conduction and convection losses. A reflector is often mounted behind the tubes to direct more sunlight onto the interior absorber pipe (see FIGURE 9-5). These collectors can produce temperatures up to 300°F (149°C), making them particularly useful for industrial applications. One design currently being tested by the Argonne National Laboratory and the University of Chicago incorporates a concentrator as an integral part of the tube. Besides increasing system efficiencies, the concentrator protects the reflective surfaces, allowing the use of highly reflective but fragile materials, such as silvered glass. A prototype operating since 1981 has produced operating efficiencies of 55% and 50%, at temperatures exceeding 300°F (149°C), with no degradation in performance.(16)

FIGURE 9-5

EVACUATED TUBE COLLECTOR



Source: David Miller and Grant Price. Solar Water Heating: A Guide for New Mexico Homeowners. Las Cruces: New Mexico Solar Energy Institute, p. 10.

Air collectors can use less expensive absorber materials than liquid collectors, since they do not have corrosion problems. Aluminum absorber plates are therefore common. The key to their recent market success is the use of small systems without storage in order to reduce costs. These systems provide heat only during the day and require a back-up heating system at night. However, the cost is very low compared to large space heating systems and, therefore, provide an inexpensive retrofit option for existing buildings.

Solar Cooling Systems

Both the government and the private sector have made a concerted research effort in solar cooling, but little commercial success was evident at the end of 1984. In general, solar-powered cooling systems need to achieve cost and performance improvements before wide-scale commercialization can occur. Work continued on the open-cycle adsorption, absorption cycle, Solar Rankine cycle, vapor jet, and closed-cycle cooling systems in 1984, with the following progress:

- An open-cycle adsorption cooling system (also known as the desiccant cooling system) has recently been commercially marketed and produced. The system consists of eight 4 feet by 8 feet (1.2 meters by 2.4 meters) collectors and a storage tank with back-up heating mechanisms. The manufacturer expects it can sell the system for $10,000 once yearly sales reach 10,000 units or more, which is less than 0.7% of the market for air conditioners.(1)(4)

- Absorption cycle systems suffer from high costs, up to $20,000 for a 3-ton capacity air conditioning system. Conventional absorption cycle systems operate best at input temperatures of 250-300°F (121°C-149°C), which is above the 180°F (82°C) upper limit for efficient flat plate collector operation. Some manufacturers are producing collectors capable of producing temperatures of 250-300°F (121°C-149°C) to increase the system efficiency.(4)(5)(12)

- Solar Rankine cycle cooling system costs must be substantially reduced before they can be competitive with conventional cooling systems. One problem is expensive component parts, such as the turbine and geartrain, which are not commercially available for solar cooling applications. Rankine systems also have efficiencies of only 6-8% and because of their need for large centrifugal compressors (over 100 tons), they may be practical only for large installations.(6)(5)

- A long-planned vapor jet prototype has yet to be built, although the plans have not been abandoned.(5)(6)

- Closed-cycle adsorption systems were being developed and marketed by a private firm in the early 1980s, but the firm has abandoned the concept.(6)(5)

In general, solar cooling systems can be made to function well; however, current technology has long payback periods. Newer systems, such as the desiccant wheel, show some promise, but the market is not developed and technology improvement across many fronts is needed.

GOVERNMENT SUPPORT

Federal research and development support for solar heating and cooling comes from the Solar Buildings Division of the Office of Conservation and

SOLAR HEATING AND COOLING

Renewable Energy, U.S. Department of Energy. For Fiscal Year 1985, the solar heating and cooling research and development budget was $4.8 million, down 42% from FY 1984 (see TABLE 9-2 and FIGURE 9-6).

TABLE 9-2

U.S. DEPARTMENT OF ENERGY FUNDING FOR SOLAR HEATING AND COOLING RESEARCH AND DEVELOPMENT, BY PROGRAM
($ millions)

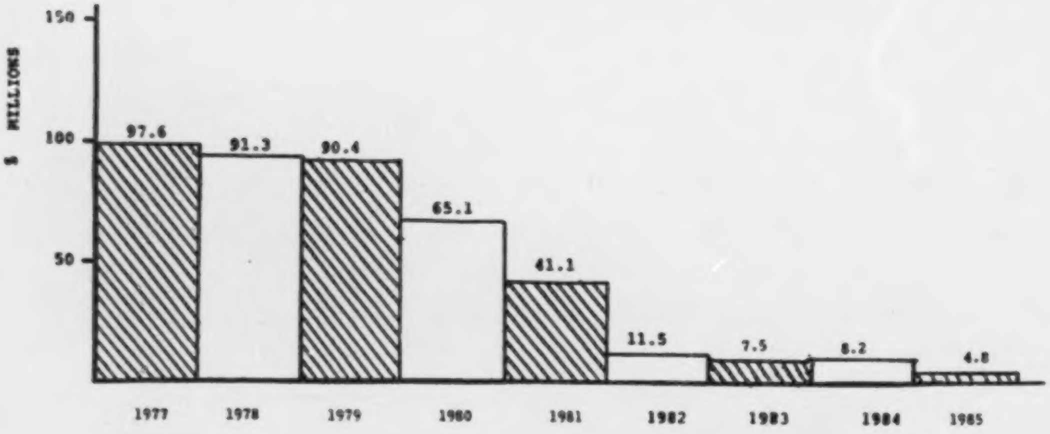
	FY83	FY84	FY85*
Materials and Component Research	3.733	5.025	2.450
Systems Research	2.935	2.620	1.820
Program Management	0.825	0.556	0.527
TOTAL	7.493	8.201	4.797

* From FY85 Annual Operating Plan for the Office of Solar Heat Technologies, March 1985.

Source: Renewable Technologies Program Summaries. Deputy Assistant Secretary for Renewable Energy, U.S. Department of Energy (DOE/CE-0105), November 1984, p. 4.

FIGURE 9-6

U.S. DEPARTMENT OF ENERGY SOLAR HEATING AND COOLING RESEARCH AND DEVELOPMENT FUNDING, FY 1977 - FY 1985



A 15% federal business energy tax credit for investments in solar heating and cooling systems, and a 40% residential energy tax credit (limited to $4,000, or 40% of a $10,000 investment) for solar heating and cooling systems expired at the end of 1985. Forty-five states offer incentives for the installation of solar heating and cooling systems (see APPENDIX I).

INDUSTRY STATUS

According to the U.S. Energy Information Administration (EIA), 224 companies manufactured solar collectors in 1984, a net gain of 21 companies relative to 1983 (see TABLE 9-4).(7) Virtually all solar collector manufacturers fall into one of two categories: subsidiaries of large (Fortune 500) corporations, or small companies that produce only solar products. Due to stagnant or declining markets, the involvement of large corporations seems to be declining. Eighty percent of collector manufacturers employ less than 15 people.(9) Overall, the manufacturers employed 3,485 full-time and 218 part-time people in 1984, an increase from 1982 when there were 2,390 full-time and 170 part-time employees.(8)

Solar collector manufacturing is highly concentrated. In 1984, the five largest producers accounted for one-third of the total output, and the top ten accounted for over half of all collector production in 1984. The industry can be divided into low-temperature, medium-temperature, high-temperature, and cooling sectors:

- The low-temperature part of the industry includes 48 manufacturers. The five largest account for 86% of total production. Total 1984 sales were about $50 million.
- 206 companies manufactured medium temperature collectors in the U.S. in 1984, with no company controlling more than 10% of the market. The top ten manufacturers--with sales ranging from about $5 million to $70 million each--accounted for 48% of 1984 sales. The top 36 manufacturers accounted for 75% of 1984 medium temperature shipments.(7)
- Fewer than ten companies produce high temperature or specialty collectors, and no information is readily available on market share (see *SOLAR THERMAL*).

- Solar cooling systems remained in a research and development phase in 1984. However, one U.S. company plans to produce and market an open-cycle desiccant cooling system (see TECHNOLOGY STATUS).

About 50 companies serve as suppliers to the solar heating and cooling industry. Fewer than ten companies produce each of the major components of a solar system—pumps, controllers, glass, absorber plates, tanks, and frames. A handful of engineering firms design solar systems for commercial applications. Small commercial systems are usually designed by the manufacturer. Because of high marketing costs, industry research and development is very limited and is concentrated mostly on developing new collector materials, e.g. polymers and thin films.

In the 1970s, most manufacturers sold their collectors through distributors, and installations were made by independent contractors. Although the industry has moved toward greater vertical integration, the industry still relies on distribution companies to sell its products.(7)(8) According to the Solar Energy Industries Association, there are an estimated 6,000 retail distribution businesses, employing approximately 30,000 people in administrative, sales, installation, and service positions.(8)

California and Florida are the leading collector manufacturing states (by location of company headquarters). New York, Colorado, and Arizona are also major sources of manufacturers (see TABLE 9-3).

TABLE 9-3

1983-84 SHIPMENTS IN THE TOP FIVE STATES
(By Location of Company Headquarters)

Location	Collectors Shipped (1000 ft2) 1984	1983	1984 Market Share	1983 Market Share
California	5,725	6,579	35%	39%
Florida	3,093	2,886	19%	17%
New York	1,454	1,968	9%	12%
Colorado	818	718	5%	4%
Arizona	767	890	5%	5%

Source: Solar Collector Manufacturing Activity 1984. Energy Information Administration, U.S. Department of Energy (DOE/EIA-0174[84]), August 1985, p. 8.

MARKET STATUS

After growing rapidly during the late 1970s, the solar heating and cooling market in the U.S. shrunk slightly during the 1980s. Most of the decline came in the low-temperature market, which matured early and appears to be reaching saturation (see TABLES 9-4 and 9-5). All told, approximately 65 million ft^2 (6.04 million m^2) of low temperature collectors and 75 million ft^2 (6.97 million m^2) of medium temperature collectors had been installed in the United States between 1974 and 1984. Based on an average collector output of 120,000 BTU/ft^2/yr, approximately 17 trillion BTUs (0.017 quads) of energy was produced in 1984, or the equivalent of 3.1 million barrels of oil, at a value of more than $80 million.

TABLE 9-4

SOLAR COLLECTOR MANUFACTURING

(Thousands Ft^2)

	Number of Active Manufacturers	Low Temperature	Medium Temperature*	Total
1974	45	1,137	137	1,274
1975	131	3,026	717	3,743
1976	186	3,876	1,925	5,801
1977	321	4,743	5,569	10,312
1978	340	5,872	4,988	10,860
1979	349	8,395	5,857	14,251
1980	233	12,233	7,165	19,398
1981	203	8,677	11,456	20,133
1982	265	7,476	11,145	18,621
1983	203	4,853	11,975	16,828
1984	224	4,479	11,939	16,419

* Includes high temperature and "special" collectors, such as evacuated tube designs.

Source: Solar Collector Manufacturing Activity 1984, Energy Information Administration, U.S. Department of Energy (DOE/EIA-0174[84]), August 1985, p. 5.

TABLE 9-5

SALES OF SOLAR COLLECTORS

(Thousands \$ 1984)

	Low Temperature	Medium Temperature*	Total
1974	\$ 12,507	\$ 10,275	\$ 22,782
1975	33,286	53,775	87,061
1976	42,636	144,375	187,011
1977	52,173	417,675	469,848
1978	64,592	374,100	438,692
1979	92,345	439,275	531,620
1980	134,563	537,375	671,938
1981	95,447	859,200	954,647
1982	82,236	835,875	918,111
1983	53,383	898,125	951,508
1984	49,269	895,425	944,694

* Includes high temperature and "special" collectors, such as evacuated tube designs.

Note: Estimates are based on the information presented in the Solar Collector Manufacturing Activity published by the Energy Information Administration. Assumes average size and cost to the final consumer as follows: Low temperature system cost of \$3400-3500 for 320 ft^2, or \$11/ft^2, and medium temperature system cost of \$4500 for 60 ft^2, or \$75/ft^2.

Source: Jeffry J. Erickson. Statistical Analysis of the Solar Energy Industry. Washington, D.C.: Solar Energy Industries Association, July 1985, p. 3.

The solar collector market has changed considerably in the 1980s (see TABLES 9-6 and 9-7). Shipments of hot water heating systems almost doubled between 1980 and 1983 before declining slightly in 1984, while pool heating system shipments peaked in 1980, decreasing 63% between 1980 and 1984. Overall, hot water system shipments accounted for 54% of overall solar collector shipments in 1984, as compared to 27% for pool heating systems. This shift in the market is, in part, due to the ineligibility of pool heating systems for federal and many state tax incentives.

SOLAR HEATING AND COOLING

Beginning in 1981, passive solar systems for domestic water heating began gaining market share, particularly in warmer climates. Industry observers estimate that passive systems accounted for more than half of all solar water heater installations in California, Arizona, and New Mexico in 1984, while capturing more than 20% of the entire U.S. solar water heater market.(1)

Another major market shift was the success of air collectors in 1984. The number of air collector designs certified by the Solar Rating and Certification Corporation increased from 12 in 1983 to 34 in 1984. A separate survey counted 54 designs in 1984.(1) Sales jumped from 774,000 ft^2 (71,906 m^2) in 1983 to 1.9 million ft^2 (176,515 m^2) in 1984. In 1984, 65% of all collectors used for space heating were air systems.(1) Virtually all the collectors sold were for small systems with no storage which satisfy only a small portion of a home's heating needs.

Early cooling system installations were primarily federal demonstration projects. The precipitous drop in sales reflects the phase out of government funding (see TABLES 9-6 and 9-7). A significant private sector market for cooling has yet to develop.

TABLE 9-6

ESTIMATES OF SOLAR HEATING AND COOLING SYSTEM INSTALLATIONS

(No. of Systems)

Year	Pool Heating	Hot Water	Space Heating	Space Cooling
1978	21,457	40,307	6,759	738
1979	22,237	47,444	6,704	957
1980	31,281	76,828	6,572	643
1981	25,436	115,547	7,853	1,683
1982	18,295	119,397	9,215	301
1983	12,584	149,534	8,106	103
1984	11,513	143,231	9,227	49

Source: Jeffry J. Erickson. Statistical Analysis of the Solar Energy Industry. Washington, D.C.: Solar Energy Industries Association, July 1985, p. 10.

TABLE 9-7

ANNUAL SHIPMENTS BY END USE

(Thousands of Ft^2)

	Pool Heating	Hot Water	Space Heating	Space Cooling	Other*	Total
1978	8,251	2,513	1,736	179	268	10,635
1979	8,551	2,958	1,722	232	789	14,251
1980	12,029	4,790	1,688	156	733	19,398
1981	9,781	7,204	2,017	408	723	20,133
1982	7,035	7,444	2,367	73	1,703	18,621
1983	4,839	9,323	2,082	25	559	16,828
1984	4,427	8,930	2,370	12	680	16,419

* Includes educational and institutional applications.

Source: Solar Collector Manufacturing Activity 1984, Energy Information Administration, U.S. Department of Energy (DOE/EIA-0174[84]), August 1985, p. 14.

Likewise, most of the commercial and industrial installations of the 1970s and early 1980s were federally funded, but this funding declined in the 1980s. The recent growth in commercial and industrial solar systems was in part due to the involvement of third party financiers, who took the federal (and state, if applicable) renewable energy tax credits and shared the energy savings with the end-user. Uncertainty over the possible extension of the federal renewable energy tax credits diminished interest in the commercial and industrial sector in 1984 (see TABLE 9-8).

TABLE 9-8

ANNUAL SHIPMENTS BY MARKET SECTOR

(Thousands of Ft^2)

Year	Residential	Commercial	Industrial	Other*	Total
1978	8,905	1,848	163	285	10,492
1979	11,387	2,015	314	547	14,251
1980	16,077	2,417	488	415	19,398
1981	15,773	2,561	1,518	282	20,133
1982	13,729	3,789	560	542	18,621
1983	11,780	3,039	1,665	344	16,828
1984	13,980	2,091	289	59	16,419
TOTALS	90,821	17,760	4,997	2,474	116,142

* Includes shipments to distributors.

Source: Solar Collector Manufacturing Activity 1984. Energy Information Administration, U.S. Department of Energy (DOE/EIA-0174[84]), August 1985, p. 17.

The most important factor in maintaining residential solar heating and cooling system sales during a period of relatively low conventional energy prices has been aggressive direct marketing. In 1981, companies began intensifying direct sales efforts, sending sales representatives to the homes of prospective buyers. The direct sales technique spread through the industry, using phone banks, direct mail, and leaflets to generate leads. Since this is an expensive marketing strategy, company overhead costs, in many cases, have increased enough to offset any savings due to reduced manufacturing costs.

International Activity

International trade in solar collectors has never been very significant. Design and production is simple enough that most countries have the ability to produce collectors domestically. In addition, shipping costs add significantly to individual system costs. The United States exported about one million ft^2 (92,903 m^2) of collectors per year in the period between 1978-80, but total exports dropped to less than 350,000 ft^2 (32,516 m^2) in 1984, about 2% of U.S. production.(7)(9) Imports, meanwhile, have grown steadily, from 235,000 ft^2 (21,832 m^2) in 1980 to 621,000 ft^2 (57,693 m^2) in 1984--amounted to less than 4% of total U.S. sales in 1984.(7)

TABLE 9-9

U.S. COLLECTOR IMPORTS AND EXPORTS

(Thousands Ft^2)

	Imports	Exports
1978	395.6	839.9
1979	290.4	854.9
1980	235.0	1,115.1
1981	196.0	771.0
1982	418.0	455.0
1983	511.0	159.0
1984	621.0	348.0

Source: Solar Collector Manufacturing Activity 1984. Energy Information Administration, U.S. Department of Energy (DOE/EIA-0174[84]), August 1985, p. 4.

Reliable information on collector sales in other countries is hard to find. Perhaps the largest market is in Israel, where regulations were implemented in 1983 requiring solar water heating systems in all new residential buildings, hotels, hospitals, and educational institutions.(17) Consequently, 33% of Israeli homes had solar water heating in 1983, and the figure is expected to reach 60% by the mid-1980s.(11) Elsewhere, the Japanese reportedly sell 500,000 passive solar water heaters a year.(1) The French produce about 700,000 ft^2 (65,032 m^2) of solar collectors a year. Over 1,000,000 ft^2 (92,903 m^2) of collectors are sold annually in Italy and Greece.(17) In Cyprus, 90%, or 88,000 individual homes had solar hot water systems as of August 1983.(18)

SOLAR HEATING AND COOLING

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Chapter 10

SOLAR THERMAL

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SOLAR THERMAL

TECHNOLOGY DESCRIPTION

Solar thermal systems convert sunlight into thermal energy which can be used for generating mechanical and electrical energy, providing industrial and agricultural process heat, or producing or refining chemicals and fuels. There are five different solar thermal systems can produce thermal energy from solar radiation: solar ponds,* hemispheric bowls, central receivers, parabolic troughs, and parabolic dishes. Except for solar ponds, all operate on the same principle: sunlight strikes a flat or curved reflective or refractive surface (the concentrator) and is focused onto a receiver that heats a thermal transport fluid, e.g. air, oil, water, molten salt, liquid metal (e.g., sodium or sodium potassium), or molten nitrate salt. A heat exchanger or a system of heat exchanging pipes (the energy transport system) transports the thermal energy to an end use or to a heat engine to produce mechanical or electrical energy.

Solar ponds collect and store solar heat in large bodies of water. The system is optimized for thermal energy production by inhibiting evaporation and convective heat loss via a density gradient of salt or similar soluble materials, or through the use of a surface insulating layer (see FIGURE 10-1).(2) Both designs use energy transport systems to move the thermal energy to an energy conversion mechanism (e.g. heat engine) or directly to an end-use application.

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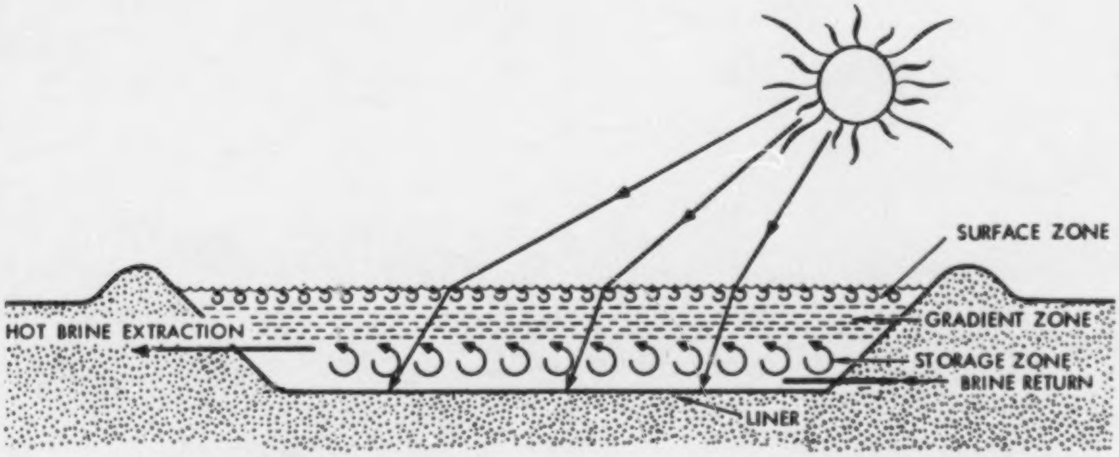
* The U.S. Department of Energy does not consider solar ponds a concentrating solar thermal technology but instead classifies it as a flat plate technology (less than 213°F).

FIGURE 10-1

SALT-GRADIENT SOLAR POND



Source: Solar Thermal Energy: State-of-the-Art. U.S. Department of Energy, Washington, D.C., 1980.

There are several distinct designs of concentrating solar thermal systems. The shapes of the components used in collecting and concentrating solar radiation help differentiate line-focusing systems (e.g., parabolic troughs), and point-focusing systems (e.g., parabolic dishes, central receivers, and hemispheric bowls).

- *Parabolic troughs*, or refractive lens linear focus systems, are long, curved, U-shaped collectors that focus solar radiation onto a tube running along the collector's focal line (see FIGURE 10-2). To maximize solar radiation collection, horizontal-axis sun tracking systems are often used.

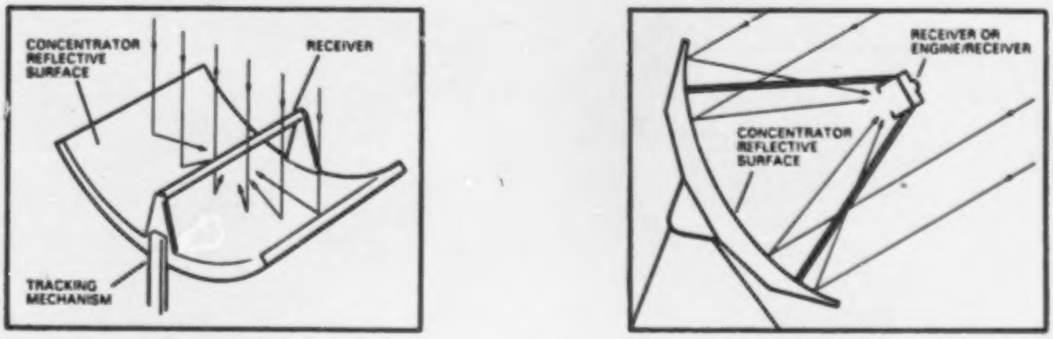
- *Parabolic dishes* are dish-shaped, dual-axis tracking mirrors or refractive lens that concentrate sunlight onto an opening in the receiver, heating the thermal transport fluid in the receiver's coils (see FIGURE 10-2). The fluid can be transported to an end-use, or electricity can be generated directly by integrating a heat engine with the receiver.

- *Central receiver systems* use a field of dual-axis tracking mirrors (heliostats) to concentrate solar radiation onto a tower-mounted receiver (see FIGURE 10-2). The individual heliostats focus the sun's rays onto the receiver by tracking the sun.

- *Hemispheric bowl systems* are large, stationary, spherical concentrators that focus sunlight onto a receiver suspended above above the bowl (see FIGURE 10-2). Unlike parabolic troughs, parabolic dishes, and central receivers, hemispheric bowls rely on the receiver instead of the concentrator to move relative to the sun.

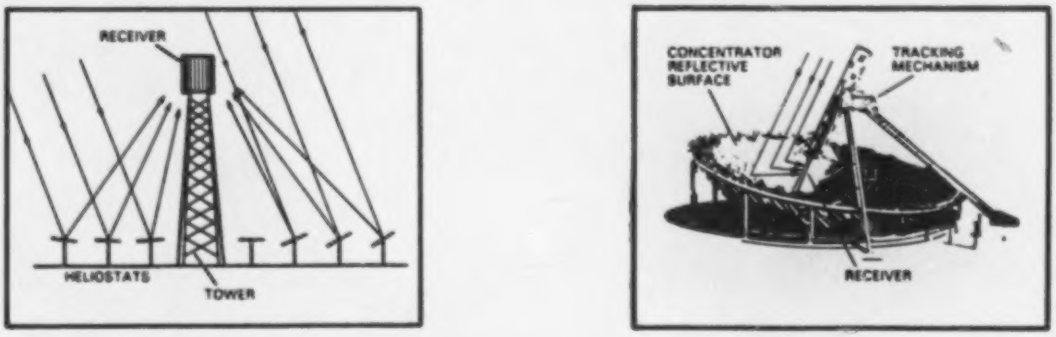
FIGURE 10-2

CONCENTRATING SOLAR THERMAL SYSTEMS


CONCENTRATOR REFLECTIVE SURFACE
RECEIVER
TRACKING MECHANISM
RECEIVER OR ENGINE/RECEIVER
CONCENTRATOR REFLECTIVE SURFACE

Parabolic Trough

Parabolic Dish


RECEIVER
HELIOSTATS
TOWER
CONCENTRATOR REFLECTIVE SURFACE
TRACKING MECHANISM
RECEIVER

Central Receiver

Hemispheric Bowl

Source: Solar Thermal Technology: Annual Evaluation Report (Fiscal Year 1983), Solar Energy Research Institute, U.S. Department of Energy, August 1984, p. 2.

APPLICATIONS

Solar ponds (up to 200°F) can be used for residential and commercial space and/or water heating, industrial and agricultural process heat, desalination, electricity production, and cooling if the heat generated by solar ponds powers an absorption chiller.

Parabolic trough (up to 750°F) applications include industrial or agricultural process heating, enhanced oil recovery, irrigation pumping, and electricity production, usually in the form of multiple units connected to an utility grid.

Parabolic dishes (up to 1830°F) may be used for water pumping, agricultural and industrial process heating, producing or refining fuels and chemicals, and generating electricity, either in single units for remote power needs or in multiple units connected to a grid.

Central receivers (1100°F-2700°F) may be used as large, utility-scale electricity generating plants for refining and producing fuels and chemicals, or for industrial process heat.

Hemispheric bowl (up to 1000°F) applications include process heat and electric power generation.

TECHNOLOGY STATUS

The concept of concentrating the sun's rays to generate heat has been a subject of research for thousands of years. The Greeks, Romans, and Chinese built curved mirrors which focused solar radiation onto an object, producing enough heat to cause it to ignite within seconds.

The first attempts at producing mechanical or electrical energy utilizing concentrated solar radiation did not occur until the late 1800s. In 1878, Augustin Mouchot introduced a solar powered printing press at the World's Fair in Paris using a parabolic reflector. In 1901, Aubrey

SOLAR THERMAL

Eneas produced a 700 ft^2 (65 m^2) collector that powered a 10 horsepower solar steam engine for water pumping at an ostrich farm in Pasadena, California. A more powerful solar water pump (50 horsepower) using parabolic troughs was designed by Frank Schuman in 1913 and was successfully tested at the Nile River in Meadi, Egypt. Enthusiasm in commercializing concentrating solar thermal systems lagged due primarily to the availability of inexpensive, conventional fuels.(5)(9)

Interest in concentrating solar thermal systems intensified following the energy crisis of 1973, with several governments and companies conducting research and development programs. One result of this research has been steady progress in reducing costs and increasing the performance of concentrating solar thermal systems. However, concentrating solar thermal systems still have significant ground to cover before meeting the long-term cost and efficiency goals the U.S. Department of Energy feels are necessary in order to compete with conventional sources of energy (see TABLES 10-1 and 10-2).(10)

TABLE 10-1

LEVELIZED ENERGY COSTS, CURRENT & LONG-TERM GOALS

(1984 $)

	1984		1995-2000	
System	Electric (¢/kWh)	Thermal ($/mmBtu)	Electric (¢/kWh)	Thermal ($/mmBTU)
Central Receivers	16	30	5	9
Parabolic Dishes	38	45	5	9
Parabolic Troughs	n.a.	30	n.a.	9
Solar Ponds	25*	n.a.	n.a.	n.a.

* From Commercial Status of Electrical Generation Technologies, California Energy Commission, June 1985, p. 191.

Source: National Solar Thermal Technology Program: Five-Year Research and Development Plan 1985-89 (Draft), U.S. Department of Energy, December 1984, p. 14.

TABLE 10-2

CURRENT AND LONG-TERM CAPITAL COSTS AND ANNUAL EFFICIENCIES[a]

(1984 $)

1984

	Electric		Thermal[b]	
	Efficiency	$/kW(e)	Efficiency	$/kW(th)
Central Receivers	16%	4600	48%	1300
Parabolic Dishes[c]	18%	8500	52%	1800
Parabolic Troughs[c]	n.a.	n.a.	32%	760
Solar Ponds[d]	2%[e]	5400[f]	n.a.	n.a.

1995-2000 Goals

	Electric		Thermal[b]	
	Efficiency	$/kW(e)[g]	Efficiency	$/kW(th)[g]
Central Receivers	22%	1600	56%	460
Parabolic Dishes	28%	1300	68%	470
Parabolic Troughs	n.a.	n.a.	56%	390
Solar Ponds	n.a.	n.a.	n.a.	n.a.

[a] All $/kW figures represent installed cost estimates.

[b] Includes production of fuels and chemicals.

[c] Normalized to turbine or process capable of handling peak field thermal output, including indirect costs.

[d] Estimates are derived from sources listed in notes e and f.

[e] From the California Energy Commission, Commercial Status of Electrical Generation Technologies, June 1985, p. 191.

[f] From A State-of-the-Art Study of Nonconvective Solar Ponds for Power Generation, Electric Policy Research Institute (AP-3842), January 1985, p. 7-4. Figures adjusted to 1984 $.

[g] Assumes the following capacity factors: Central Receiver (electric)-0.5; Central Receiver (thermal)-0.29; Parabolic Dish (electric)-0.26; Parabolic Dish (thermal)-0.28; Parabolic Trough (thermal)-0.24; Solar Ponds (electric)-0.56.

Source: National Solar Thermal Technology Program: Five-Year Research and Development Plan 1985-89 (Draft), U.S. Department of Energy, December 1984, p. 14.

SOLAR THERMAL

Technical Issues

Excluding solar ponds, solar thermal systems use the same concept to produce thermal energy (see TECHNOLOGY DESCRIPTION). Consequently, research and development on collecting solar radiation and energy conversion applies equally to parabolic troughs, parabolic dishes, central receivers, and hemispheric bowls. This section, therefore, applies to all of the concentrating solar thermal systems.

The collection technology of concentrating solar thermal systems encompasses the absorption and concentration of solar radiation. It is further subdivided into optical materials, concentrators, and receivers.

- *Optical materials* (mirrors and lenses) include the reflecting, refracting, and transmitting materials for concentrators and the transmitting and absorbing elements for receivers. The material currently in use--silvered glass--has the highest specular reflectance (90-95%), but is heavy and brittle, requiring extensive supporting equipment.(9) Research and development efforts are focusing on developing silvered polymers and silver steel surfaces that will be lighter in weight and easier to handle than silvered glass. By 1990, these new materials are also expected to be less expensive than the current cost of silvered glass: $\$1.40/\text{ft}^2$ ($\$15/\text{m}^2$) as compared to $\$1.85/\text{ft}^2$ ($\$20/\text{m}^2$).(10)

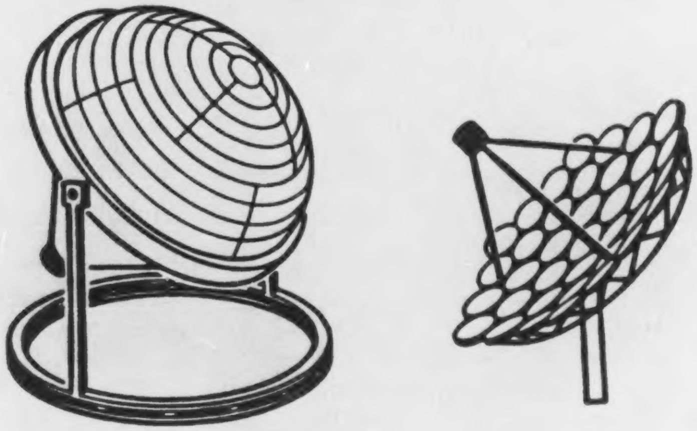
- *Concentrators* are typically the most expensive component of a solar thermal system, and their performance has a large impact on system operations. Presently, new concentrator designs are being investigated, such as the Fresnel Lens, the Innovative Point Focus concentrator, and the Stretched Film concentrator (see FIGURE 10-3).(10) All three designs are being tested by the U.S. Department of Energy, with results expected in 1987.(34)

- *Receiver* research and development has centered on finding thermal transport fluids and designs that will reduce thermal losses, increase efficiencies, and lower costs. Several thermal transport fluids have been used in currently installed solar thermal systems, including water/steam, molten salt, liquid sodium, oil, and air. These generally operate at temperatures below 1100°F (600°C) and annual energy efficiencies of 75-90%. The cost of concentrator aperture varies for each concentrating solar thermal technology: $\$7.5/\text{ft}^2$ ($\$80/\text{m}^2$) for central receivers, $\$18.50\text{-}32.50/\text{ft}^2$ ($\$200\text{-}350/\text{m}^2$) for parabolic dishes, and

$\$3.7/\text{ft}^2$ ($\$40/\text{m}^2$) for parabolic troughs.(10) The U.S. Department of Energy's 1990 goal is to reduce receiver costs by 30% for all concentrating solar thermal technologies.(10)

FIGURE 10-3

INNOVATIVE CONCENTRATOR DESIGNS



Dome Fresnel Dish

Stretched Film

Source: National Solar Thermal Technology Program: Five Year Research and Development Plan: 1985-89 (Draft), Sandia National Laboratories (Livermore), U.S. Department of Energy, December 1984, p. 17.

Energy conversion technologies are the processes and components that change thermal energy into electrical or mechanical energy. Areas of technological focus include items like heat engines and thermal storage technologies.

- *Heat engines* are the primary mechanism for converting thermal energy into electricity. Solar thermal systems have most often used Rankine cycle engines, but as receivers are designed that can withstand higher temperatures, newer heat engines are being emphasized, such as the Stirling conversion cycle.(10)

- *Thermal storage technologies* add flexibility to solar thermal systems by making them accessible for night-time use as well as daytime. Oil, oil/rock, air/rock, liquid sodium, and molten nitrate salt are all being explored as possible storage materials. Further research will be devoted to newer methods of storage and containment and heat transfer techniques.(10)

System Performance

Parabolic troughs are considered the most mature of the solar thermal technologies, with commercial installations for both thermal and electrical applications.(3) They are the solar thermal technology of choice for low-to-medium temperature thermal energy applications, achieving efficiencies of up to 70% at 572°F (300°C).(9)(48) One of the most notable significant process heat installations using troughs is the Gould facility, a privately financed system installed in Chandler, Arizona in December 1982. The 60,480 ft^2 (5,619 m^2) system has been available 94% of the time and provides 98% of the facility's process heat demand. The cost of the installation has been kept confidential, but it is estimated a similar system would now cost $2.4 million, or $40/$ft^2$ ($431/$m^2$).(14)

Yet contrary to expectations, the primary market for parabolic troughs is now electricity generation, due largely to the Solar Energy Generating System (SEGS) project that was installed in 1984 in Daggett, California. This commercial 13.8 MWe (net) system can be viewed as a hybrid solar/fossil fuel installation. Parabolic troughs are used to heat oil to 585°F (307°C), which is then circulated to a heat exchanger to produce steam. At this point, the steam is superheated to 780°F (416°C) by natural gas before being passed through a conventional steam turbine. The SEGS-I facility was built at a capital cost of $4420/kWe ($ 1983).(1) A 30 MWe SEGS-II facility, featuring third generation concentrators that have apertures twice as wide as the SEGS-I concentrators, is to be installed at the same site by the end of 1985 at an installed cost of $3200/kWe (1985 $).(1)(45).

Parabolic Dishes are considered to be the most likely solar thermal technology to contribute significantly to new electric generating capacity in the 1990s.(3) This is based on the number of firms involved with the technology, the state of the technology, and the system's modularity (installation of systems in incremental amounts).(3)

Perhaps the most technically notable achievement in 1984 was the deployment of the Vanguard dish-electric system using a Stirling heat engine. Located in Rancho Mirage, California, this system set a world's efficiency record (32% gross, 29% net) for converting sunlight into electricity and was recognized by a science research magazine as one of the 100 most outstanding technical innovations of 1984.(10)(5) The Stirling heat engine will also be tested in eight 25 kWe parabolic dish prototypes to be installed across the country by a private manufacturing company.(5)

Commercially, a 4.9 MWe parabolic dish-electric system became operational in 1984. Located in Warner Springs, California, the SOLARPLANT I system consists of 700 dishes covering 322,000 ft^2 (29,915 m^2). The field is divided into two sections. The first section produces steam at a temperature of 450°F (232°C). The steam is sent through a separator and then returned to the second section to be superheated to 700°F (371°C). The steam is then piped to two turbine generators; a primary 3.7 MWe turbine generator and a secondary 1.2 MWe generator used for start-up, peaking, and shut-down operations. Analysts have estimated that the system operates at a 13% annual efficiency and was built at a capital cost of $4326/kWe ($ 1983). One source estimated a similar system would now cost $3400/kWe if it was built today.

The SOLARPLANT I system is significant for two reasons. First, it uses the Stretched Film concentrator that is consistent with the U.S. Department of Energy's drive towards the use of lightweight, stretched membranes for parabolic dishes. Second, the system employs a centralized turbine, as opposed to dish-mounted engine systems with heat engines at the focal point of each dish. The centralized turbine approach has lower heat engine costs but is prone to thermal energy transport losses. The dish-mounted engine approach has higher initial capital costs, estimated by the U.S. Department of Energy to be $8500/kWe, but can generate higher solar-to-electric efficiencies.(10) Both designs will be tested by the U.S. Department of Energy to find the best combination of performance and cost.

Testing is underway to see whether parabolic dish systems can be compatible in an industrial application with an electric utility grid interface. The Solar Total Energy Project (STEP), installed in Shenandoah, Georgia in 1982, is designed to provide almost 3 MWth; supply 1380 lb./hr of process steam at 350°F (177°C); 400 kWe of electricity to a nearby knitwear factory; and meet part of the factory's air conditioning load. The system consists of 114 dishes, each 23 feet in diameter. The dishes heat a silicon fluid to 750°F (399°C), which is pumped to a heat exchanger where it boils and superheats water. High-pressure steam at 700°F (371°C) powers a turbine to generate electricity. Medium-pressure steam is used for knitwear pressing, and low-pressure steam runs the air conditioning system.(9) Further tests are scheduled, with commercial power production to commence in 1987.(22)

Central receiver system development has been paced largely by the 10 MWe Solar One installation in Barstow, California, an experimental facility developed in 1981 by the U.S. Department of Energy, California Energy Commission, Southern California Edison, and the L.A. Department of Water and Power. The system consists of 1,818 heliostats (dual-axis, sun-tracking mirrors) that reflect solar radiation to a receiver on top of a 250 foot (76 meters) tower, producing steam at 950°F (510°C). The thermal storage subsystems allows the facility to operate at night or in periods of low solar insolation.(9) The facility entered its power production phase in August 1984 and generated over 7000 MWhe (24 hour net) between August 1, 1984 and July 31, 1985. It is expected to generate over 10,000 MWhe (net) in the second power production phase.(46)

The Solar One facility has allowed the testing and development of several important central receiver subsystems, notably heliostats and thermal transport fluids.

- *Heliostats* are currently the most expensive subsystem of a central receiver system, but progress has been made in reducing production costs. Initial heliostat costs were \$84/ft^2 (\$904/m^2), but research and development efforts have lowered costs to \$14/ft^2 (\$151/m^2), with a 1990s goal of \$3.70/ft^2 (\$39/m^2).(9)(10) A new concentrator design, the stretched membrane heliostat, may substantially reduce heliostat costs from those installed at Solar One.(14)

  At Solar One, heliostat performance has been very good, with availabilities of 97-100%.(5)(46) Some problems with surface corrosion have been reported but have generally been minimal, considered to be the equivalent of one heliostat.(47)

- *Thermal transport fluids* have been the subject of intensive research and development in the central receiver area. First generation systems used water/steam as the transport fluid, but liquid sodium and molten nitrate salt are currently considered the preferred receiver and thermal transport fluids. Both are low-pressure liquids over their entire operating temperature range, are relatively low in cost, and can also be used directly for thermal energy storage. Sodium has better heat transfer characteristics than molten salt but is more expensive. Both fluids have to be heated at the bottom of their operating temperature range to prevent them from solidifying.(46)

As part of research and development efforts on thermal transport fluids, testing of the Molten Salt Electric Experiment (MSEE) began in 1984 at the Central Receiver Test Facility near Albuquerque, New Mexico. The molten salt, consisting of 60% sodium nitrate and 40% potassium nitrate, is considered a highly effective heat transfer fluid due to its chemical stability, heat capacity, and lack of phase change in the system's operating temperature range. The system consists of 222 heliostats that reflect solar radiation to a receiver mounted on top of a 200 foot (61 meters) tower, which heats the salt to 1050°F (566°C). Pumps send the molten salt to a hot storage tank and then to a steam generator, where the thermal transport fluid is converted to steam. The steam powers a turbine generator to produce electricity. The salt flows from the steam generator to the cold storage tank and then back to the receiver for reheating.(23)

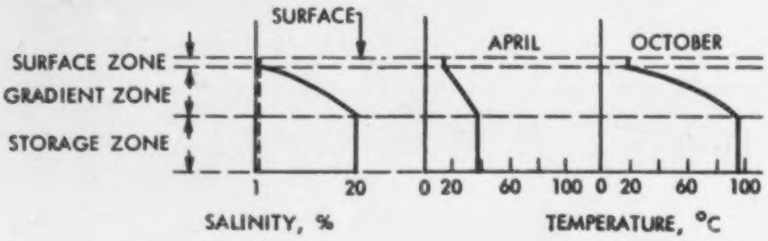
Hemispheric bowls are the least developed concentrating solar thermal technology, partly due to the low efficiency limitations caused by the basic structure of the bowl. Unlike the other solar thermal technologies that rely on sun-tracking concentrators to focus solar radiation onto a stationary receiver, hemispheric bowls have a stationary concentrator and a tracking receiver. The concentrator is shaped like a large bowl, (similar to a parabolic dish but deeper), with the receiver mounted on top. The stationary concentrator allows the construction of large units at a potentially low cost, but at the expense of incident sunlight loss, the amount of loss depending on the latitude and orientation of the reflector and the time of year. This and the thermal losses from pipes, receivers, and other components help contribute to the low efficiencies so far experienced by the hemispheric bowl technology.(9)

The phenomena of naturally-occurring salt gradient *solar ponds* was first observed by A. Von Kalecsinsky in 1902 at Medve Lake in Transylvania. The highly saline bottom layer of the lake created a salinity and density gradient that helped raise the lake's temperature to as high as 158°F (70°C).(27) The first artificially created solar pond was established in 1958 by a team of Israeli scientists.(42)

Current solar pond designs are of two basic types: "non-convecting" and "convective." Non-convecting solar ponds restrict thermal heat loss by inhibiting convection. The best known example--*salt-gradient solar ponds*--seeks to accomplish this by creating 3 distinct layers: 1) a fairly thin surface layer which is kept as thin as possible since it has no role in producing heat and, in fact, can lose heat from wind or evaporation; 2) a non-convective zone with a density, salinity and temperature gradient that increases with depth. This layer serves a dual purpose of insulation and heat collection; and 3) a homogeneous and convective bottom layer which acts as the system's thermal storage (see FIGURE 10-4). A liner, typically made of a black butyl rubber that enhances absorption of the sun's radiation, is used to prevent salt infiltration into nearby groundwater or soil.(27)

FIGURE 10-4

THE THREE LAYERS OF SALT-GRADIENT SOLAR PONDS



Source: Solar Thermal Energy: State-of-the-Art. U.S. Department of Energy, Washington, D.C., 1980.

Other non-convecting solar ponds include *membrane-stratified ponds* which employ several thin, closely spaced transparent membranes, and *gel ponds* that retard convection through a layer of gel. High capital costs have slowed development of both concepts.(28)

The best known example of a convective solar pond is the *shallow solar pond*, which features a black water bag, usually about 15 feet by 175 feet (4.57 meters by 53 meters), that is insulated with foam on the bottom and with glazing on the top.(27) The water in the bag is heated during the day and hot water can be utilized at night or sent to storage.(28) Excessive thermal transport losses have limited the development of shallow solar ponds.(27)

Two methods are employed to remove heat from a solar pond. The first, used in salt gradient ponds, pumps hot brine from the bottom of the pond into an external heat exchanger or evaporator. From here, the heat is sent to an end-use and the brine is returned to the pond for reheating The other method uses a thermal transport fluid that is piped through the pond to be heated. The fluid is then transported to an end-use.(9)

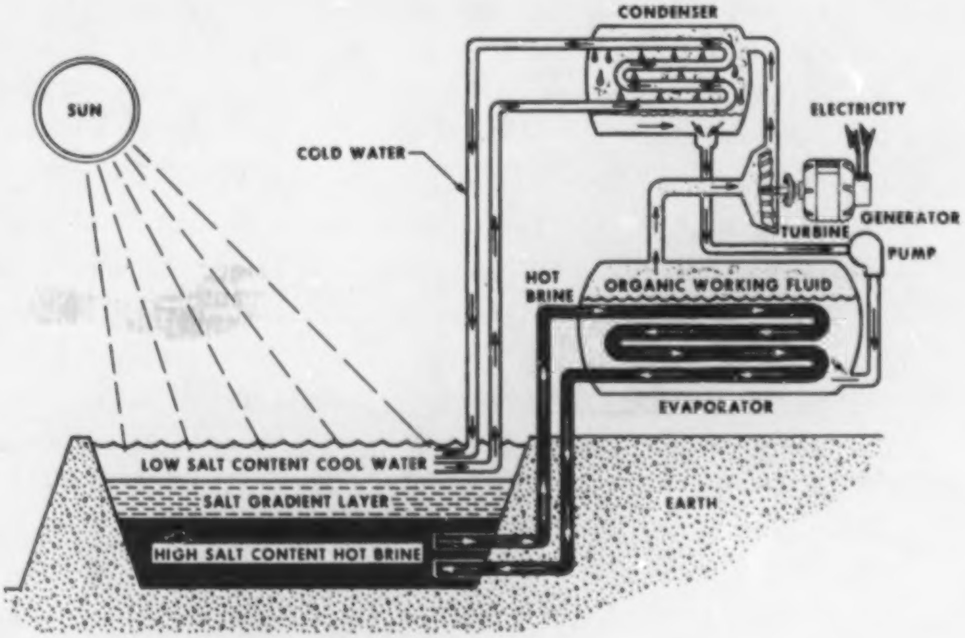
Several solar ponds of different sizes and for different applications have been built since 1974, especially in Ohio, Illinois, New Mexico, and Tennessee.(28) A 21,000 ft^2 (1,951 m^2) artificially-created salt gradient solar pond provides heat for a recreational building and swimming pool in Miamisburg, Ohio.(9) It was built for about \$3.50/ft^2 (\$38/m^2).(28) Many shallow solar ponds, ranging in size between 1200 ft^2 and 240,000 ft^2 (111 m^2 and 22,297 m^2), were built by or with the assistance of the Tennessee Valley Authority in 1982-83, at a cost varying between \$17/ft^2 and \$33/ft^2 (\$183-\$355/m^2).(43) A 20,000 ft^2 (1,858 m^2) shallow solar pond will come on-line in 1987 at Chickamauga, Georgia for \$12/ft^2 (\$129/m^2).(32)(43)

Electricity generation, using a salt gradient solar pond coupled with a closed-cycle Rankine engine, has been achieved in Israel, with system installations of 6 kWe, 150 kWe, and 5 MWe.(27) The concept uses an evaporator to vaporize the thermal transport fluid, the heat being supplied by the hot brine. After the vapor powers a turbine to generate electricity, the vapor is sent to a condenser, where it is cooled to a liquid state. The cycle is repeated when the condensed liquid returns to the evaporator (see FIGURE 10-5).(28)

Several uncertainties could limit the further development of solar ponds, the most important being capital and operating costs. Although engineering and feasibility studies have been conducted for proposed sites at the Great Salt Lake (Utah), Trascott Brine Lake (Texas), and the Salton Sea (California), no utility-scale, power-producing, solar pond facility exists in the U.S. Consequently, cost data is somewhat limited. One study by the Electric Power Research Institute concluded a 50 MWe (gross) non-convecting solar pond would have a capital cost of \$5400/kW and generate electricity at 25¢/kWh.(28)(1) Other limiting factors include the cost of salt (if needed), the capital costs of excavating and constructing the pond, and the large amounts of water and land that are required.(1)(28)

FIGURE 10-5

ELECTRICITY GENERATION USING A SALT-GRADIENT SOLAR POND


CONDENSER
SUN
ELECTRICITY
COLD WATER
GENERATOR
TURBINE
PUMP
HOT BRINE
ORGANIC WORKING FLUID
EVAPORATOR
LOW SALT CONTENT COOL WATER
SALT GRADIENT LAYER
EARTH
HIGH SALT CONTENT HOT BRINE

Source: Solar Thermal Energy: State-of-the-Art. U.S. Department of Energy, Washington, D.C., 1980.

GOVERNMENT SUPPORT

Federal research and development support for solar thermal systems comes from the Solar Thermal Division of the Office of Conservation and Renewable Energy in the U.S. Department of Energy. For Fiscal Year 1985, the solar thermal research and development budget was $35.50 million, a 18% decrease from Fiscal Year 1984 (see TABLE 10-3 and FIGURE 10-6).

SOLAR THERMAL

TABLE 10-3

U.S. DEPARTMENT OF ENERGY FUNDING FOR SOLAR THERMAL RESEARCH AND DEVELOPMENT, BY PROGRAM

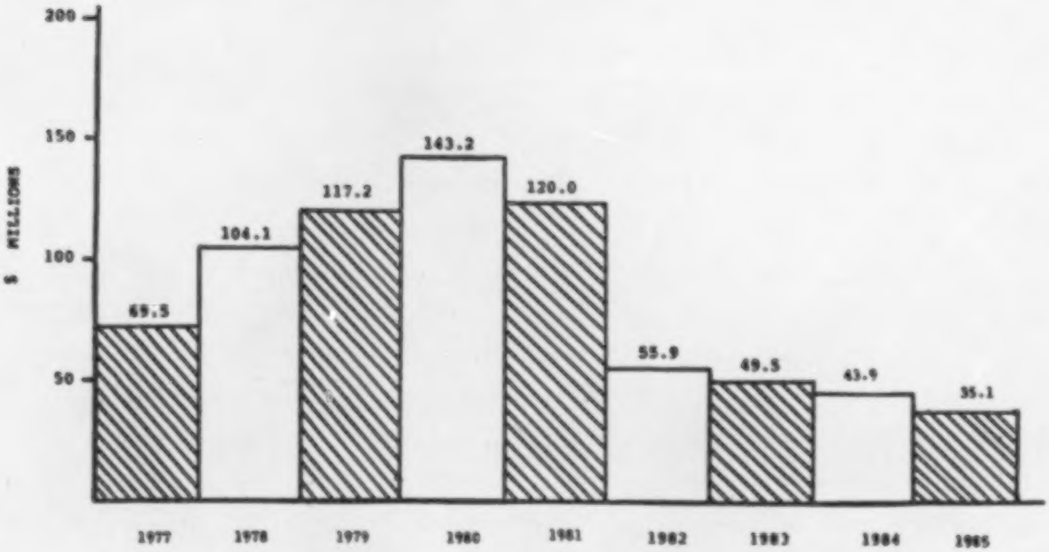
($ millions)

Program	FY84	FY85
Collection Technology	10.180	12.432
Conversion Technology	7.103	5.075
Systems and Applications Technology	24.730	15.338
Planning and Assessment	1.587	1.705
Capital Equipment	0.250	0.500
TOTAL	43.850	35.050

Source: Solar Thermal Technology Program: Fiscal Year 1986/1987 Program Review, as presented to the Subcommittee on Energy Development and Applications of the House Science and Technology Committee, February 1986, by the Division of Solar Thermal Technology, U.S. Department of Energy.

FIGURE 10-6

U.S. DEPARTMENT OF ENERGY SOLAR THERMAL RESEARCH AND DEVELOPMENT FUNDING, FY 1977 - FY 1985



The Public Utility Regulatory Policies Act (PURPA) requires utilities to buy electricity generated by non-utility small power producers at the utilities' avoided cost rates. Solar thermal power systems under 80 MWe of installed capacity qualify under PURPA.

A 15% federal business energy tax credit for investments in solar thermal energy systems, and a 40% residential energy tax credit (limited to $4,000 or 40% of a $10,000 investment) for solar thermal systems expired at the end of 1985. Thirty-nine states offer various incentives (e.g. tax credits, tax exemptions, or loans or grants) for stimulating the development of solar thermal systems (see APPENDIX I).

INDUSTRY STATUS

The industry now consists of 30 companies that are involved with researching, developing, and/or manufacturing one or more of the solar thermal technologies and/or their components. The companies range in size from small (less than 20 employees) firms to large aerospace corporations.(6) The industry has largely been dependent on federal research and development funding, although commercial sales in 1984 totaled $70 million, mostly from the SEGS I and SOLARPLANT I installations.(41)

Reflecting the uncertain market conditions, 10 companies, mostly large aerospace and energy companies, have dropped out of the industry since 1981.(6)

Parabolic Troughs

Eleven companies are involved in producing systems, research and development, or making component parts. They are almost evenly split between large corporations and small companies.(6) Commercial activity in this sector is dominated by the manufacturer of the SEGS installations in California.(3)(5)

SOLAR THERMAL

Parabolic Dishes

Twenty-one companies are involved in parabolic dish technology, mostly in research and development and component manufacturing. Like parabolic troughs, industry involvement is split between large corporations and small companies.(6) At least two companies are recent entries into this sector, having concentrated previously on central receivers or parabolic troughs.(3) Like parabolic troughs, commercial activity is presently paced by a single installation, the 4.9 MWe SOLARPLANT I facility in California. Other industry activity includes one company's installation and testing of eight individual dish-electric systems in various parts of the country.(5)

Central Receivers

Thirteen companies are active in central receiver technology, most of them large engineering, chemical, electric, or fuel production firms that received less than 1% of their overall revenues from solar thermal activities.(6) Because there are no commercially operating central receiver facilities, activity is confined to research and development on important component parts or subsystems, such as heliostats, thermal transport fluids, and storage processes.(3) Due to uncertain market conditions, three companies previously involved with central receivers dropped out of the solar thermal industry altogether in 1984, while a fourth began concentrating on parabolic dishes.(3)

Solar Ponds

Although solar pond systems rely on conventional heat engines, vaporizers, condensers, and pumps to use or convert the heat that is generated, no U.S. company has produced any of this equipment which would be compatible with dichloro tetrafluorethane, considered the best thermal transport fluid for solar pond electric systems. One company in Israel has conducted extensive research on electricity-generating solar ponds and is considered the industry leader, both technically and economically.(1) Component research in the U.S. is conducted by related industries (e.g., liner research by the synthetics industry). System research has been limited to existing solar pond sites.

Hemispheric Bowls

Activity is limited mostly to government and university research, due to problems with low efficiencies and component failures detailed in TECHNOLOGY STATUS. The technology is still in a research and development stage, with no commercial activity presently planned.

MARKET STATUS

Parabolic Troughs

Up until 1984, market penetration for parabolic troughs was thought to be most likely in the industrial process heat sector, due to their high thermal efficiencies (see TECHNOLOGY STATUS); however, market potential for parabolic troughs in this sector is likely to be affected by declining oil prices. The near-term market potential for parabolic troughs has now shifted from industrial process heat to peak power production. In 1984, one facility alone, the 13.8 MWe SEGS-I electricity generating facility in California, approximately equaled the total capacity of central receivers, parabolic dishes, and other parabolic troughs currently used for generating electricity.(5) An additional 30 MWe is scheduled to come on-line with the installation of the SEGS-II facility in late 1985. Five more SEGS facilities totaling 150 MWe are scheduled to be built by 1990, although it is recognized that realization of this schedule will be sensitive to market factors, including tax law provisions and the cost of competing conventional power, as measured by "avoided cost" calculations under PURPA (see GOVERNMENT SUPPORT).(5)

SOLAR THERMAL

Parabolic Dishes

Market activity in 1984 in the parabolic dish sector was dominated by the 4.9 MWe SOLARPLANT I facility in California. Some pilot projects are being carried out in electric, remote power, and process steam applications which may have market penetration possibilities in the near future.(5) Two important projects are the Small Community System Experiments, under which the U.S. Department of Energy is planning to install two 100 kWe dish-electric systems in Osage City, Kansas and Molokai, Hawaii in Fiscal Years 1987 and 1988, and the installation of eight individual dish-electric systems across the country by a large aerospace corporation.(5) One source is projecting 0.4-200 MWe of installed capacity in the U.S. for parabolic dish-electric systems by 1995.(3)

Central Receivers

No commercial central receiver system is currently in operation anywhere in the world. Analysts in the private and public sector have stressed the need for a commercial-scale demonstration central receiver plant to overcome cost and performance uncertainties surrounding the technology.(3) Private efforts to finance three such plants, ranging in size between 30-100 MWe, have been unsuccessful.(5) Efforts are now being jointly undertaken by three utilities, in cooperation with the U.S. Department of Energy, to formulate a 1990s commercial central receiver system design.(47)

Solar Ponds

The only known commercial electricity-generating plant utilizing solar ponds is a 5 MWe facility at Beith Haarava on the Dead Sea in Israel. The company that installed it has proposed a 12 MWe plant on Danby Lake in California, if financing can be secured.(1) In general, the market for electricity-generating solar ponds appears limited in the U.S., primarily due to low electric efficiencies and, consequently, the large required land area.(28) Other ponds providing thermal energy, mostly for research and development purposes, have been operating since 1974 (see TECHNOLOGY STATUS).

Hemispheric Bowls

No commercial installations currently exist for this technology, and none currently planned. Potential markets include industrial process heat (at temperatures up to 1000°F (538°C) and electricity generation; however, they will be competing with other, more commercially developed solar thermal technologies.

International Activity

The SEGS parabolic trough facilities have been installed by a U.S. company that is closely affiliated with a firm in Israel that developed the technology. Likewise, solar pond electric systems have been developed using Israeli technology. With parabolic dishes, foreign input to U.S. activity is limited to the Stirling heat engine, which is produced in Sweden and exclusively licensed to a corporation in the U.S.(5) Internationally, West Germany has a cooperative research and development agreement on parabolic dish-electric systems with Saudi Arabia. Australia has an experimental dish-thermal power plant near White Cliffs in New South Wales.(48) Some interest has been expressed in Germany, Spain, Italy, and France on central receivers, with the International Energy Agency (IEA) operating a 500 kWe central receiver system in Almeria, Spain.(5)

SOLAR THERMAL

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Chapter 11

WIND ENERGY

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WIND ENERGY

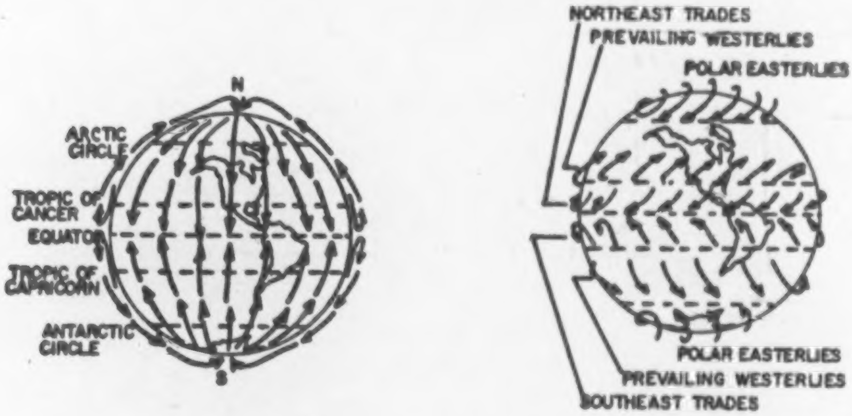
RESOURCE AVAILABILITY

Wind is the movement of air caused by the uneven heating of the earth's surface by the sun. Because warm air is less dense than cooler air and tends to rise while cooler air sinks, the movement of air (wind) occurs as a result.(9) This is further accentuated by the tilt of the earth's axis and its rotation around the sun. Because of this rotation, different areas of the earth are heated at different rates during different times of the year, leading to changes in wind direction and velocity.(27)

Worldwide wind distribution occurs largely from warm air rising near the equator that is replaced by cooler air from the poles. The earth's rotation causes wind to move counterclockwise in the northern hemisphere, clockwise in the southern hemisphere (see FIGURE 11-1).(27)(39)

FIGURE 11-1

EFFECTS OF THE EARTH'S ROTATION ON WIND DIRECTION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POLAR EASTERLIES
POLAR EASTERLIES
PREVAILING WESTERLIES
SOUTHEAST TRADES

Wind Circulation if Earth did not Rotate

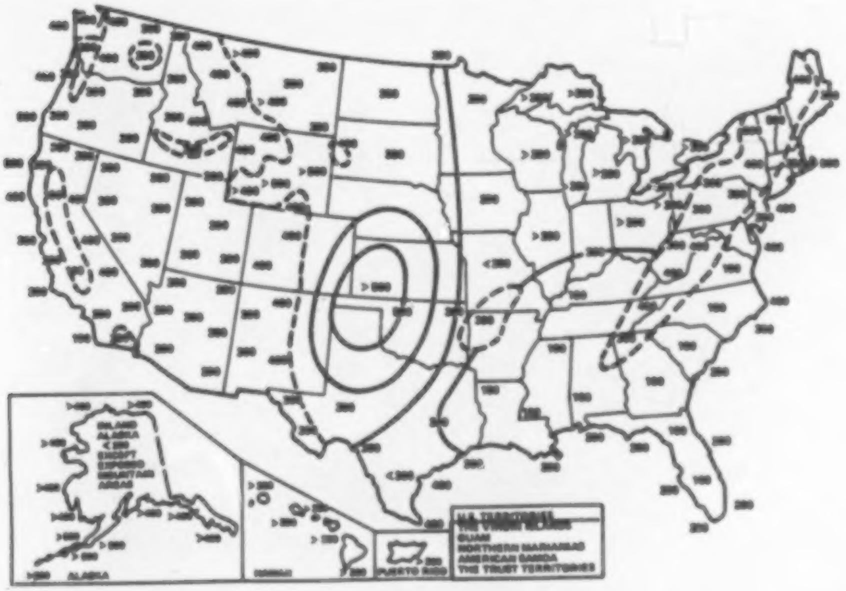
Wind Circulation as Affected by Earth's Rotation

Source: Nicholas P. Cheremisinoff. Fundamentals of Wind Energy. Ann Arbor, Michigan: Ann Arbor Science, 1979, p. 3.

WIND

The potential for electricity generation from wind in the U.S. is enormous. A solar energy panel from the National Science Foundation and the National Aeronautics and Space Administration (NASA) estimated that the potential power available from surface winds over the continental U.S., the eastern seaboard, and the Aleutian Arc is about 100,000 gigawatts (GW). This compares to the current U.S. electric capacity of 672 GW.(60) Near-term potential for wind energy generation in the U.S. is equally impressive. One study estimates that 210 GW could be installed in the U.S. by the year 2000, generating 1-2 trillion kWh of electricity annually, enough to supply 13.6% of the anticipated U.S. electricity demand.(1) Other sources, while not so optimistic, nevertheless predict that 20,000-21,000 MW (20-21 GW) could be installed by the turn of the century.(51)(55) The prime wind resources in the U.S. are in California, Texas, Oklahoma, and the Northeast, but Michigan, Kansas, and the Northwest also show promise (see FIGURE 11-2).(51)

FIGURE 11-2
U.S. AVERAGE ANNUAL WIND POWER
(watts per m^2 at 50 meters)



Source: Wind Energy Systems Program Summary. Office of Solar Power Applications, Assistant Secretary for Conservation and Solar Energy, U.S. Department of Energy (DOE/CS/20097-01), May 1980, p. 9.

WIND

Reliable estimates of worldwide wind potential are not available, but it is generally acknowledged that the potential far exceeds current worldwide electricity consumption.(27) Good wind resources exist in the plains regions of China, northern Europe, and the Soviet Union; along the coastlines of northwest Africa and western South America; and on islands in the Caribbean and Mediterranean.(55)

The potential for mechanical wind systems is also high since they can take advantage of more marginal wind resources. They are found in most parts of the world.(55)

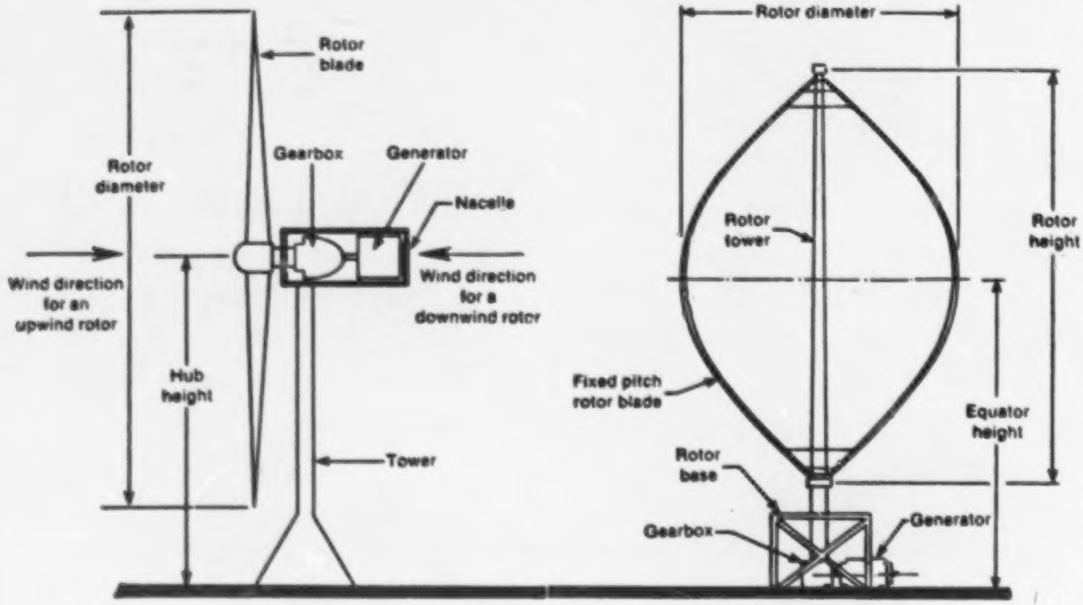
Assessing wind potential, though, can be difficult. Wind velocity can change dramatically from year to year, from season to season, and even during one day with little warning. Research in Hawaii has shown that mean annual wind speed can vary as much as 65% over a ten-mile radius, while another study showed 20-40% annual variations in total energy potential from wind at one site in Amarillo, Texas.(27)

TECHNOLOGY DESCRIPTION

A wind energy conversion system consists of a rotor (the assembly of the blades, hub and shaft), a gear box, a tower, control equipment, and power conditioning equipment if the system is used to produce electricity. The system can produce mechanical energy directly through shaft power, or electric energy by turning a generator or, in some cases, a generator and a gearbox.

Wind turbines can be divided into two types: *horizontal-axis*, in which the axis of the rotor's rotation is parallel to the ground, and *vertical-axis*, in which the axis of rotation is perpendicular to the ground (see FIGURE 11-3). Horizontal-axis turbines can be subdivided into upwind and downwind turbines, depending on where the blades are located in relation to the tower and the direction of the wind. Upwind turbines intercept the wind prior to the tower, while the wind passes the tower in downwind systems before reaching the rotor.

FIGURE 11-3
HORIZONTAL-AXIS AND VERTICAL-AXIS WIND TURBINES


Rotor blade
Rotor diameter
Gearbox
Generator
Nacelle
Wind direction for an upwind rotor
Wind direction for a downwind rotor
Hub height
Tower
Rotor diameter
Rotor tower
Rotor height
Fixed pitch rotor blade
Equator height
Rotor base
Gearbox
Generator

Horizontal-Axis Vertical-Axis

Source: Five Year Research Plan: 1985-1990. Wind Energy Technology Division, U.S. Department of Energy (DOE/CE-T11), January 1985, p. 2.

A further distinction between horizontal- and vertical-axis turbines is the need of the horizontal systems to orient, or "yaw" the rotor in response to changing wind directions. Wind systems can use a free or passive yaw, like a tail vane or rudder, or an active or driven yaw that is controlled by microprocessors. Because vertical-axis turbines can accept wind from any direction, they do not need to be yawed.

Wind-electric systems produce electricity by transmitting the rotational energy of the rotor to a generator or alternator. A gearbox is normally added in larger machines to increase rotational speed. Wind systems must also include some sort of braking system to protect wind systems from high winds or extreme weather conditions. Because the electrical output of wind-driven power systems varies in frequency, synchronous generators or induction generators are used to convert it to utility-grade power.

Mechanical systems use wind power directly, turning a shaft to pump water or grind grain. Although vertical-axis turbines have been used for mechanical applications, mechanical wind systems are usually horizontal-axis, multi-bladed turbines popularly called *windmills*.

Direct heat systems also use wind power directly, rotating a shaft to agitate fluids or air to create heat.

APPLICATIONS

Historically, *mechanical systems* have been used to pump water for irrigation or domestic consumption, for food processing, and to desalinate sea water.

Direct heat systems can provide heat for homes or businesses. They can also be used in agricultural applications, such as drying crops, processing milk and food, or protecting plants or trees from frost.(39)

Electrical systems can be applied to a variety of purposes, with application being mostly a function of rated turbine generating capacity (the power a wind machine will produce operating at a specific wind speed):(39)

- *Small systems* (1-2 kW or less) are typically used in remote areas, where utility-provided power is either unavailable or very costly. The wind turbines charge batteries that in turn power telecommunications, navigation, or military equipment, or supply power to homes or small businesses.
- *Residential/Agricultural systems* (3-40 kW) can provide household electricity or heat, or they can be used for agricultural functions, such as drying grain, pumping water, or supplying process heat.
- *Utility-size systems* (15 kW-2500 kW and over) can be used to generate electricity, either in groups (wind farms) or alone in remote locations.

TECHNOLOGY STATUS

Wind has a long history of mechanical applications, primarily for agricultural processes. The Egyptians used wind around 2800 B.C. to grind grain and to lift water. From there, the use of wind spread to Persia and throughout the Middle East and Europe.(40)(39) In the U.S., the Spanish were the first to use windmills, although the English popularized them by authorizing the Surveyor General to set aside a half-acre of land for any farmer who wanted one. Windmills eventually became an important energy source for the U.S., supplying up to 25% of the non-transportation energy in the 1850s.(27) However, wind energy use in the U.S. declined sharply after the Rural Electric Administration began connecting rural areas to central utility stations in the 1930s and 1940s.(13)(27) Except for a 1.25 MW system built by Palmer Putnam in the 1940s in Rutland, Vermont, market activity was limited mostly to mechanical wind systems.(27)(40)

A renewed interest in wind energy occurred after conventional energy prices rose sharply in the 1970s. Federal legislation helped establish an industry of independent generators who could sell the output of their systems to a local utility (see GOVERNMENT SUPPORT). To maximize power production and to lower costs, these independent developers began multiple installations in specific locations, referred to as wind farms. The development of wind farms has played a major role in creating a domestic wind industry in the United States. The substantial growth in wind farms (see MARKET STATUS) has given companies the economies-of-scale necessary to reduce system costs, as well as providing enough income to design and build bigger and more powerful turbines (see TABLE 11-1). For example, the average rotor size at Altamont Pass in California, currently the largest wind farm in the world with 2800 wind turbines, increased two-fold between 1982 and 1984, and the generating capacity per square meter of swept rotor area jumped 40%.(15)

WIND

TABLE 11-1

AVERAGE SYSTEM SIZE AND INSTALLED COST OF WIND SYSTEMS IN CALIFORNIA

	1981	1982	1983	1984
Average Size of Turbines (kW)	49	56	69	78
Installed Cost ($/kW)	3113	2175	1900	1860

Source: California Energy Commission, Wind Industry Trends, Dec. 1984.

Wind system performance seems to be making steady progress, as measured by increasing system availability, steadily improving capacity factors, and decreased operation and maintenance costs (O&M):

- Wind system availability has improved from 0-70% in 1981-82 to 80-97% in 1984.(58) More mature systems are achieving availabilities of 95-98%.(59)
- Capacity factors currently range from 5-25%. More mature systems are consistently achieving capacity factors of 22-25%.(25)
- O&M costs for current wind systems averaged 1.5¢/kWh in 1984, as opposed to 3¢/kWh in 1981. O&M costs are expected to decrease further to 1¢/kWh by 1985 or 1986.(58)

The combination of improving performance and decreasing system costs has led to a drop in the cost of wind-generated electricity. At Altamont Pass in California, the cost of wind-generated electricity was 12¢/kWh in 1984, as opposed to 17¢/kWh in 1981-82.(15) In general, it is estimated that commercial wind systems were producing electricity at a cost between 10-15¢/kWh in 1984, excluding tax subsidies.(3) Over time, the cost of wind-generated electricity is expected to decline even further. A report prepared by the California Energy Commission estimated wind-generated energy costs will range between 2.5-3.5¢/kWh for investor-owned utilities, and 1.8-2.6¢/kWh for publicly-owned utilities between 1990 and 2020 (all cost figures in 1984 $).(50)

WIND

Research and development is continuing on why wind energy production differs widely among turbines. Energy production from wind turbines has generally been 5-30% below rated capacity, with individual system production varying as much as 100%.(42) These results have been attributed to:

- *Inadequate siting*. Some wind systems are installed in areas of low wind speed or where there are problems with turbulence.
- *Wind/wind system interaction*, such as solidity losses and wake effects.(42) Solidity losses occur when wind encounters the systems but gradually moves up and over the turbine, lowering the amount of wind that could be converted into energy.(43) Wake effects result from turbines upwind extracting energy from the wind, lowering wind speeds for turbines located downwind.
- *Design and mechanical problems*, such as operating "off-yaw," (the yaw failing to position the wind system into the wind), or dirty or soiled blades which can cause energy losses of 5-20%.(44)

Other research efforts include the development of variable speed generators; advanced airfoils, drive trains, and control systems; and research on the wind resource itself, e.g., atmospheric fluid dynamics and aerodynamics.(3)

Research is also continuing on very large wind systems. Since 1977, four large, horizontal-axis wind systems have been tested--the MOD 0-A (200 kW), MOD-1 (2 MW), WTS-4 (4 MW), and the MOD-2 (2.5 MW)--in an attempt to commercialize large wind systems that can produce substantial amounts of electricity at costs comparable to conventional electricity-generating facilities.(47) These tests were marred by equipment malfunctions, causing system shutdowns that delayed the gathering of data crucial to the design and construction of a new large wind system, the MOD-5 (3.2 MW). Faced with impending cutbacks in federal funding, a surplus of power capacity and declining worldwide oil prices, two major companies dropped plans to develop a multi-megawatt wind system.(49) An important step, though, may be taken with the proposed 1986 installation of a 3.2 MW MOD-5B on Kahuku Point in

Hawaii.(16) The system relies on better understood components to help defray the high construction and operating costs.(47)

GOVERNMENT SUPPORT

Federal research and development support for wind systems comes from the Wind Energy Division of the Office of Conservation and Renewable Energy at the U.S. Department of Energy. For Fiscal Year 1985, the wind research and development budget was $29.1 million, a 10% increase over Fiscal Year 1984 (see TABLE 11-2 and FIGURE 11-4).

TABLE 11-2

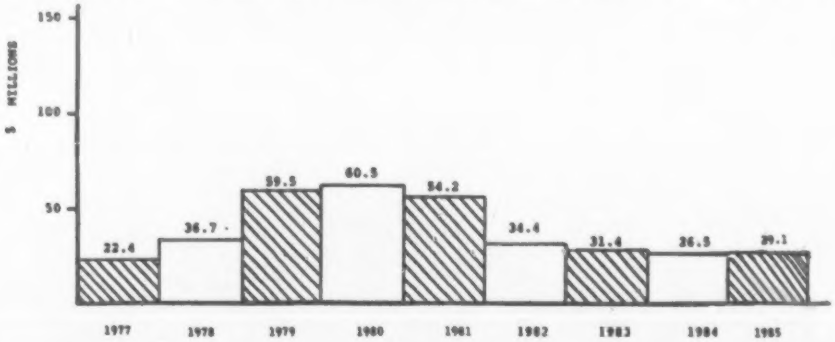
U.S. DEPARTMENT OF ENERGY FUNDING
FOR WIND RESEARCH AND DEVELOPMENT, BY PROGRAM
($ millions)

Program Area	FY83	FY84	FY85
Aerodynamics Research	2.5	3.8	8.0
Structural Dynamics Research	2.4	2.9	5.5
Systems Analysis	0.7	0.3	0.7
Wind Energy Research Center	2.0	1.5	1.7
MOD-2 Development	5.7	2.0	0.0
MOD-5 Development	18.0	16.0	13.0[a]
Capital Equipment	0.1	0.0	0.2
TOTAL	31.4	26.5	29.1

Source: Renewable Technologies Program Summaries. Deputy Assistant Secretary for Renewable Energy, U.S. Department of Energy, (DOE/CE-0105), November 1984, pp. 49-54.

FIGURE 11-4

U.S. DEPARTMENT OF ENERGY
WIND RESEARCH AND DEVELOPMENT FUNDING, FY 1977 - FY 1985



The Public Utility Regulatory Policies Act (PURPA) requires utilities to buy electricity generated by non-utility small power producers at the utility's avoided cost rates. Wind energy conversion systems (alone or in a wind farm) of less than 80 MW of installed capacity generally qualify.

A 15% federal business energy tax credit has been available for investments in wind energy systems, and a 40% residential energy tax credit (limited to $4,000, or 40% of a $10,000 investment) expired at the end of 1985. Thirty-seven states offer various incentives for the development and installation of wind systems (see APPENDIX I).

INDUSTRY STATUS

Mechanical Wind Systems

The mechanical wind systems industry reached its peak in the late nineteenth century when 77 factories were operating (mostly around Chicago), and windmills were being exported overseas. One hundred and thirty-one firms served the mechanical wind system market before World War I; there are now three.(1)

Electrical Wind Systems

Sixty companies are currently manufacturing complete wind-electric systems in the United States.(1) The top ten companies produce an average of 200 systems a year. Most of the remaining firms are in an early development stage and produce fewer systems as a result. Approximately 15 manufacturers account for 80% of all U.S. production of wind turbines.(1)

The continuing increase in wind system installations has created a market for component suppliers, resource analysts, and siting consultants. In 1984, there were 100 component suppliers, 15 siting service companies, and 25 resource measurement equipment businesses related to wind. The trend, however is towards vertical integration in the wind industry with the manufacturers taking responsibility for manufacturing, project development, installation, and system operation and maintenance.(1)

The northeastern and Great Lakes states, along with California, accounted for most of the wind system industry and its suppliers. Southern states like Texas and Oklahoma also contain wind system manufacturers and component suppliers.(1)

MARKET STATUS

Wind Farms

Almost all of the market activity in wind systems since 1981 has been due to wind farms developed for the sale of electricity to utilities, using individual wind turbines ranging in capacity from 15 kW-600 kW. In 1984, the energy produced from wind farms was 10 times the amount of energy generated from all other wind applications.(1) Ninety-five percent of the United States' and 75% of the world's installed wind capacity is in California for these reasons:

- The presence of several prime wind areas. The California Energy Commission has noted five so far, and three (Altamont, Tehachapi, and San Gorgonio) have generated 96% of the wind energy in the U.S.(17)(37)
- The relative availability and ease of buying and leasing prime wind resource land in California for wind system development.
- A reliance by the state on high-priced fuel (oil and gas) which provides high avoided cost payments under PURPA regulations.
- The presence of state energy tax credits in supplementing federal energy tax credits (see APPENDIX I).

The rate of growth in electricity production from wind has been dramatic. In 1982, California wind farms produced 4800 MWh. This increased 40 fold to over 188,000 MWh in 1984. Consequently, the equivalent of over 31,000 homes had their average monthly electricity needs serviced by wind turbines in 1984, as opposed to 800 in 1982.(56)

Growth in unit and dollar sales in the United States (primarily California) has been equally explosive (see TABLE 11-3). Nationwide, it is estimated more than 8,500 wind systems have been installed with a capacity of over 600 megawatts (see TABLE 11-4).(1)

TABLE 11-3

U.S. UNIT AND DOLLAR SALES BY YEAR, 1981-84

Year	Unit Sales	Dollar Sales (Millions Current $)
1981	1001	n.a.
1982	1408	120
1983	2673	400
1984	3753	750

Source: Jeffry Erickson and Carlo La Porta. Energy Innovation: Development and Status of the Renewable Energy Industries - 1985. Washington, D.C.: Solar Energy Industries Association, December 1985.

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TABLE 11-4

NUMBER AND INSTALLED CAPACITY OF WIND TURBINES IN THE U.S. (Through 1984)

Location	Turbines Installed	MW Capacity
California*		
Altamont	3,893	317.5
San Gorgonio	2,447	150.2
Tehachapi	1,946	131.6
Other	183	10.1
California Total	8,469	609.4
Non-California**	92	4.3
Total	8,561	613.7

Sources: * California Energy Commission, Summary of Large Scale California Wind Projects: 1981-84 (Fact Sheet), December 1984.

** E.M. Dickson (Strategies Unlimited), Wind Power Stations: 1984 Survey. Electric Policy Research Institute (AP-3963), June 1985, p. S-4.

Hawaii may become another significant user of wind-generated electricity. As of 1984, 300 small wind systems provided nearly 5 MW of generatiang capacity in Hawaii. The Hawaiian Electric Company has signed agreements for wind installations totaling 8.8 MW or 7% of the utility's capacity.(16)

Small Wind Turbines

While the market for wind farms has been one of substantial growth, the market for small wind systems rated under 5 kW has generally declined, especially in the residential/agricultural markets. 1984 sales dropped 72% by one estimate, and some companies have left this market in favor of larger wind systems.(1) Many small system manufacturers are aiming at the domestic and international remote power market which has high potential. In 1983, remote wind systems totaled almost 11 MW worldwide, or about 1% of world remote renewable energy capacity. Remote wind installations are expected to grow at a rate of 18% annually, accounting for about 42 MW by 1991.(25)

Large Wind Turbines

Large, multi-megawatt machines have had numerous operating problems (see TECHNOLOGY STATUS). High costs, uncertain government funding, and the technical complexity of these systems will most likely delay or prevent significant market penetration of multi-megawatt machines in the U.S. for at least the next 5-10 years.(46)

Mechanical Wind Turbines

More than 6 million mechanical wind systems were installed between 1850 and 1970, 150,000 of which are still being used today.(3)(27) By the 1900s, though, mechanical wind systems began losing their competitive edge to gasoline machines that could not only pump water but could feed grinders, wood saws and other farm machinery. Two events--the Great Depression and the establishment of the Rural Electrification Administration--essentially eliminated both the foreign and domestic markets for mechanical wind systems. Many companies folded or entered other markets.(48)

Currently, three companies manufacture and market mechanical wind systems in the U.S., and none of the three rely on wind turbines as their sole commercial activity. Sales are concentrated mostly in rural areas in the midwestern, western, and southwestern United States. Forecasts are for the market to remain stable, with possibly a small increase should oversea markets expand.(52)

Direct Heat Systems

Although direct heat wind systems have been successfully tested by the University of Massachusetts and other universities, commercialization attempts so far have failed. In September of 1984, the last company marketing direct heat wind systems announced it was abandoning them to produce wind-electric systems. One reason cited was the low price of heating oil, which was 3 times less than the cost of wind-generated heat.(1)

International Activity

Denmark has the second largest concentration of wind systems in the world with 467 units.(12) A survey of 429 of these systems indicated that 28.6 MWh were produced in 1984, enough to supply 7,145 homes.(10) Wind system companies are the fastest growing industry in Denmark today numbering 20 firms and employing 1,500 people.(11)(22)

Danish exports have grown rapidly and has become very important to Denmark's wind industry. In 1984, exports (mainly to the U.S.) accounted for 79% of shipments (see TABLE 11-5). It is estimated that Denmark's share of the U.S. wind market increased to 25-30% in 1984 from 10-15% in 1983. Factors cited in this growth include the reliability of the Danish machine, and a favorable exchange rate resulting from the strength of the U.S. dollar.(1)

TABLE 11-5

DANISH SHIPMENTS OF WIND SYSTEMS, 1980-84

No. of Wind Systems

	1981	1982	1983	1984
Domestic	196	163	230	300
Exports	10	40	340	1100
Shipments	206	203	570	1400

Source: James Levitt (Resource Planning Associates), International Renewable Energy Industry and Trade Policy: A Competitive Assessment. Cambridge, MA: Resource Planning Associates, Jan. 1985, p. 3.1.18).

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Due to the strong demand in the domestic market, U.S. exports of wind systems have been limited.(22)(2) Smaller wind system manufacturers are beginning to become more active in exporting, with systems installed or being installed in remote areas of Barbados, Canada, Morocco, Tunisia, Egypt, Oman and Australia.(2) Testing of remote wind systems is being conducted by Thailand and Saudi Arabia.(23)

Activity is not just limited to small wind systems, as interest in wind farms for remote or utility-connected power has been reported in Mexico, Tunisia, Spain, China, and Portugal.(2) Perhaps the country with most active interest in exploiting wind in the near term is India. Besides devoting one million dollars between 1983 and 1984 for wind, India has scheduled the installation of pilot wind farms in the coastal state of Gujarat in 1985, and is offering 25-50% cash subsidies for those who buy wind systems.(26)

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APPENDIX I

State Renewable Energy Incentives

Many publications survey the availability of state tax incentives for renewable energy systems. However, most focus on a narrow niche, such as tax credits, or a particular technology or group of technologies (e.g. solar). This appendix is intended to give a survey of available state incentives for all renewable energy technologies: biomass, alchohol fuel, refuse-to-energy, geothermal, hydro, ocean, solar, passive, and wind systems. Information was gathered by a survey of 50 states and 6 U.S. territories conducted by the Renewable Energy Institute in mid-1985, with follow-up telephone calls in February of 1986. Information was obtained by all but Puerto Rico and Vermont is included here. The information is current through the end of December 1985.

Part I is a matrix listing the available incentives by state and by type of incentive. Incentives were broken down as follows:

- State tax credits are subdivided into business (B) and residential (R) applications.
- State tax exemptions (sales or property tax exemptions, elgibility for Industrial Development Bonds, or exemption from the state gasoline tax for alcohol fuels) and tax deductions were given the code E.
- All other incentives (loans, grants, solar access or favorable building codes, and licensing and permitting incentives) were coded O.

Part II gives specific information on the availability and restrictions of each state's tax incentives. It also lists the address and phone number of the state energy office, and the name of the person who returned the survey.

The information given in this Appendix is meant only to be a guide, not a comprehensive survey of each state's incentives for renewable energy development. Consequently, we urge individuals with questions about particular incentives to contact the state directly.

PART I

Codes: B=Business Income Tax Credit; R=Residential Income Tax Credit; E=Other Tax Incentives; O=Other Incentives, i.e. Loans, Grants, etc.

State	Biomass	Alcohol Fuels	Refuse to Energy	Geothermal	Hydro	Ocean	Solar	Passive	Wind
Alabama	R,O,E	E	E	---	---	---	R	R	---
Alaska	O	---	---	B	B,O	---	B	O	B,O
American Samoa	B,R	B	B	B,R	B	B	B,R,O	---	B,R
Arizona	---	---	---	---	---	---	B,R,E	R,O	---
Arkansas	---	---	---	---	---	---	---	---	---
California	E,O	B,E	O	O	O	---	B,R	R	B,R
Colorado	B	B,E	---	B,R,E	---	---	B,R	R,O	B,R,E
Connecticut	E,O	E	E	---	E	---	E	E,O	E,O
Delaware	---	---	---	---	E	---	R,E	---	---
Dist. of Col.	---	---	---	---	---	---	---	---	---
Florida	O	E	O,E	---	---	---	E,O	O	---
Georgia	---	---	---	---	---	---	B,R,E	B,R,O	---
Guam	---	---	E	---	E	---	B,R	---	B,E
Hawaii	E	E	---	E,O	E	---	B,R,O	O	B,R
Idaho	R	B	---	R	---	---	R	R	R
Illinois	---	E	---	---	---	---	E	---	---
Indiana	---	E,O	---	B,R,E	B	---	B,R,E	B,R,O	B,R
Iowa	---	E	---	---	E,O	---	E	O	O
Kansas	---	E	---	---	---	---	B,R	R	B,R
Kentucky	---	E	---	B,R	---	---	B,R	R	B,R
Louisiana	E	E	E	E	E	E	E	E	E
Maine	---	E	E	---	E	---	R	---	R,E
Maryland	---	---	---	---	---	---	E,O	---	---
Massachusetts	E,O	---	---	E	E	---	R,E	R	B,R,E
Michigan	R	E	---	---	---	---	R	R,O	R
Minnesota	O	E	---	---	E	---	R	R,O	R
Mississippi	O	---	O	---	---	---	E	O	---
Missouri	---	---	---	---	---	---	---	O	---
Montana	R,E,O	E,O	B,O	R,E	R,E	---	R,O,E	R	B,R,E
Nebraska	---	E	---	---	---	---	B,R	R,O	B,R
Nevada	E	E	---	E	E	---	---	---	E
New Hampshire	E	---	---	---	E	---	E	---	E
New Jersey	---	---	---	---	---	---	E	O	E
New Mexico	---	E	---	B,R,O,E	E,O	---	B,R	R,O	B,R
New York	---	---	---	E	O	---	R	R	B,R,E,O
North Carolina	B,R,O	B,R	---	---	B,R	---	B,R,O,E	B,R	B,R,O
North Dakota	---	E	---	B,R,E	---	---	B,R,E	R	B,R,E
N. Marianas	O	---	---	---	---	---	O	O	---
Ohio	B,E	E	B,E	B,R,E	---	---	B,R,E	R,O	B,R,E
Oklahoma	---	---	---	---	---	---	B,R	B,R	B,R
Oregon	B,O	O	O	B,R,E,O	B,O	O	B,R,O,E	R,O	B,R,E
Pennsylvania	O	---	---	---	---	---	---	---	---
Puerto Rico	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Rhode Island	---	---	---	---	B,E	---	B,R,E	R,O,E	B,R,E
South Carolina	B,R	---	B	B,R	B	---	B,R	R	B,R
South Dakota	E	E	---	E	E	---	E	O	E
Tennessee	O	E	---	---	---	---	---	---	---
Texas	E	E	E	E	E	E	E	O	E
Utah	B	E,O	B	---	B,E	---	B,R	R,O	B,R
Vermont	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Virginia	---	---	---	---	---	---	R,E,O	R	R
Washington	E	E	E,O	E	E	E	E	E	E
West Virginia	---	---	---	---	---	---	---	---	---
Wisconsin	---	---	O	---	E	---	B,R	R,O	B,R,E
Wyoming	---	---	---	---	---	---	---	---	---

PART II

ALABAMA

Alabama Department of Economic and Community Affairs
Energy Division
PO Box 2939
Montgomery, AL 36105
(205) 284-8950
Contact: Fred Braswell

Tax Credits: Residential--10% for solar systems up to a maximum credit of $1000, declining 5% each year. Scheduled to expire December 31, 1985. For passive, 1/2 the credit for solar systems.

Business--none.

Other Tax Incentives: Taxpayers may deduct cost of wood-fired systems if used as a primary heat source in place of gas or electricity.

Industrial Revenue Bonds can be issued for refuse-to-energy facilities.

Gasoline containing alcohol fuels taxed 3¢/gallon less.

Other Incentives: Loan program for biomass projects.

ALASKA

Division of Community Development
Energy Programs Office
3601 C St. Suite 722
Anchorage, AK 99503
(907) 563-1955
Contact: Steve Baden

Tax Credits: Residential--none.

Business--35% for solar, geothermal, hydro, and wind. No known minimum, no expiration date.

Other Tax Incentives: None.

Other Incentives: Loans available for biomass, hydro, and wind projects.

Solar access laws for passive solar.

APPENDIX I

AMERICAN SAMOA

Territorial Energy Office
Office of the Governor
Pago Pago, American Samoa 96799
01-684-699-1325
Contact: Drury Samia

Tax Credits:	Residential--40%, up to a maximum credit of $4,000 for solar, wind, biomass, and geothermal. Scheduled to expire December 31, 1985. Business--15% for solar, geothermal, ocean, and wind; 10% for biomass, refuse-to-energy, alcohol fuels, and hydropower. Scheduled to expire December 31, 1985.
Other Tax Incentives:	None.
Other Incentives:	None.

ARIZONA

Arizona Solar Energy Commission
1700 W. Washington St. Rm. 502
Phoenix, AZ 85007
(602) 255-3683
Contact: James Warnock and Ray Williamson

Tax Credits:	Residential--25% (in 1985), maximum credit of $1000, for solar and passive. Decreases 5% each year. Expires December 31, 1987. Business--25% (in 1985), no limit, solar. Decreases 5% each year. Expires December 31, 1987.
Other Tax Incentives:	Property tax exemption for residential and business installations of solar systems.
Other Incentives:	Favorable building code and solar access provisions for passive solar at the option of local governments.

APPENDIX I

ARKANSAS

Energy Office
One Capitol Mall
Little Rock, AK 72201
(501) 371-1370
Contact: Morris Jenkins

Tax Credits:	None.
Other Tax Incentives:	None.
Other Incentives:	None.

CALIFORNIA

California Energy Commission
1516 9th St.
Sacramento, CA 95814
(916) 324-3469
Contact: Michael DeAngelis

Tax Credits:	Residential--10% for solar, passive, and wind up to a maximum credit of $1,000. For multi-family dwellings, the credit is 25% of total cost. Expires December 31, 1986. Business--25% for solar, no maximum. For wind systems purchased before August 1, 1985 and installed on or before December 31, 1985, with no maximum. For systems purchased after August 1, 1985 and installed on or by December 31, 1985, the credit is 25% but only 1/3 of the amount can be taken in 1985. The remaining two-thirds must be taken in one-third increments in 1986 and 1987. Expires December 31, 1986. A 55% credit, up to $1,000, is available for the conversion of an automobile to run on methanol or ethanol. This credit expires in 1991.
Other Tax Incentives:	4.5¢ per gallon exemption for alcohol fuels. Biomass fuels exempt from state sales tax.

Other Incentives: Zero Interest Loan program for commercial biomass facilities.

Total financing available for refuse-to-energy facilities.

Geothermal loan and grant program.

COLORADO

Office of Energy Conservation
112 E. 14th Ave.
Denver, CO 80203
(303) 866-2507
Contact: Karen George

Tax Credits: Residential--30% credit for solar, passive, geothermal, and wind systems, up to a maximum credit of $3,000. Photovoltaic systems ineligible. Dual purpose passive solar designs qualify for 30% of half the building or building modification costs. Scheduled to expire December 31, 1985.

Business--30% credit for wind and solar; 10% for biomass, alcohol fuels and geothermal. No known maximum credit. Expires December 31, 1986.

Other Tax Incentives: 5¢/gallon exemption from state gas tax for alcohol fuels.

Local government option to exempt alcohol fuel, wind and geothermal systems from property tax.

Other Incentives: Favorable building codes and solar access laws at the option of local governments.

CONNECTICUT

Office of Policy and Management Energy Division
80 Washington St.
Hartford, CT 06106
(203) 566-2800
Contact: Michael Sartori

Tax Credits: None.

Other Tax Incentives:	Businesses that manufacture, sell, or install solar, wind, hydro, and biomass systems are exempt from the state business tax. 1¢/gallon gas tax exemption for alcohol fuels. Local option to exempt passive solar designs and residential hydro systems from property taxes. Sales tax exemption for biomass central heating systems, refuse-to-energy systems, hydro systems, passive solar designs, and wind systems.
Other Incentives:	Low-interest loans for passive solar designs and residential biomass, solar, and wind systems.

DELAWARE

Division of Facilities Management/Energy
Department of Administrative Services
P.O. Box 1401
O'Neill Building
Dover, DE 19903
(302) 736-5644
Contact: Ed Shimamoto

Tax Credits:	Residential--$200 credit for solar domestic hot water systems only. No expiration date. Business--none.
Other Tax Incentives:	Solar and commercial hydropower systems can qualify for Industrial Revenue Bonds.
Other Incentives:	None.

DISTRICT OF COLUMBIA

Government Energy Office
420 7th St. NW, 5th Floor
Washington, DC 20004
(202) 727-1830
Contact: Jack Werner

Tax Credits:	None.
Other Tax Incentives:	None.
Other Incentives:	None.

APPENDIX I

FLORIDA

Governor's Energy Office
301 Bryant Building
Tallahassee, FL 32301
(904) 488-6764
Contact: None Given

Tax Credits: None.

Other Tax Incentives: Solar and alcohol fuel systems exempt from sales tax.

Residential solar systems exempt from property taxes.

Alcohol fuels exempt from state gas and sales taxes.

Investment tax credits available for refuse-to-energy systems.

Other Incentives: Loans available for passive solar designs, solar, biomass, and refuse-to-energy systems. Programs conducted mostly by utilities.

Grants available for residential biomass systems.

Favorable building codes and sola access laws for passive solar designs.

GEORGIA

Governor's Office of Energy Resources
270 Washington St., SW
Atlanta, GA 30334
(404) 656-5176
Contact: Rene Dziejowski

Tax Credits: Residential--20%, up to a maximum credit of $1000 for solar and passive solar design, except passive solar space heating, which is eligible for a 10% credit. Expires December 31, 1989.

Business--Same as residential.

Other Tax Incentives:	Property tax exemption for residential solar systems at option of local government. Residential solar systems exempt from state sales tax.
Other Incentives:	Solar access and building codes for passive solar design.

GUAM

Guam Energy Office
P.O. Box 2950
Agana, Guam 96910
(671) 734-4452
Contact: Dr. Douglas R. Smith

Tax Credits:	Residential--40% for domestic hot water and photovoltaic systems. Scheduled to expire December 31, 1985. Business--Same as residential, except wind farms are eligible for a varying tax credit with no expiration date.
Other Tax Incentives:	Qualifying refuse-to-energy and hydro projects eligible for tax rebates through the Guam Economic Development Authority. Property tax exemption for wind systems at option of local governments.
Other Incentives:	None.

HAWAII

Department of Planning and Economic Development
Energy Division
P.O. Box 2359
Honolulu, Hawaii 96804
(808) 548-4150
Contact: Dr. Takeshi Yoshihara

Tax Credits:	Residential--10% for solar and wind systems. Increases to 15% in 1986 should the federal renewable energy tax credits not be renewed. Expires December 31, 1992. Business--Same as residential.

Other Tax Incentives: Sale of electricity from biomass, geothermal, hydro, and wind taxed at producer's rate of 0.5%, instead of general excise tax of 4%.

Ethanol sales exempt from state general excise tax until June 30, 1992.

Other Incentives: None.

Waiver of geothermal royalties (up to 10% of the resource's value) for up to 8 years.

IDAHO

Department of Water Resources
Statehouse
Boise, ID 83720
(208) 334-3721
Contact: Terry Hayden

Tax Credits: Residential--none.

Business--0.8% credit for five years for ethanol fuels and equipment used to produce it. Must use Idaho agricultural products or by-products. No expiration date.

Other Tax Incentives: Residential--40% deduction for the first year, declining to 20% for the following three years for solar, passive solar design, geothermal, biomass (wood stoves only) and wind. Equivalent to a 7% tax credit in a 20% tax bracket. Maximum credit of $5,000 per year. Wind systems must be used for space heating only. No expiration date.

Other Incentives: None.

ILLINOIS

Department of Energy and Natural Resources
Energy and Environmental Affairs Division
325 West Adams St. Room 300
Springfield, IL 62706
(217) 785-2800
Contact: David Loos

Tax Credits: None.

Other Tax Incentives: For property taxes, residential property with a solar system can be assessed with a conventional energy system or with the solar system, whichever is less.

6% exemption from sales tax for alcohol fuel systems.

Other Incentives: None.

INDIANA

Indiana Department of Commerce
Division of Energy Policy
One North Capitol, Suite 700
Indianapolis, IN 46204
(317) 232-8940
Contact: Monica Cannaley

Tax Credits: Residential--25%, up to a maximum credit of $3,000, for solar, passive solar designs, geothermal, and wind systems. State quality and performance standards must be met. Costs unique to passive solar design eligible for credit--dual purpose components (e.g., building structure) ineligible. Wind and photovoltaic systems must generate at least 37 watts under certain conditions to qualify. Expires December 31, 1987.

Business--25%, up to a maximum credit of $10,000, for solar, passive solar designs, geothermal, hydro, and wind. Costs unique to passive solar design eligible for credit--dual purpose components (e.g., building structure) ineligible. No minimum temperature required for geothermal. Power generating equipment of hydro facilities are only eligible for credit; dams are not eligible. Wind and photovoltaic systems must generate a minimum of 37 watts under certain conditions to qualify. Expires December 31, 1987.

Other Tax Incentives: Property tax deductions for residential solar systems and commercial and residential geothermal systems.

1¢ sales tax exemption for gasoline containing ethanol.

Other Incentives: 15¢/gallon subsidy for qualified ethanol producers.

Solar access laws for passive solar designs.

APPENDIX I

IOWA

Energy Policy Council
Lucas State Office Building
Des Moines, IA 50319
(515) 281-4420
Contact: None Given

Tax Credits: None.

Other Tax Incentives: Residential solar systems exempt from property taxes for five years.

1¢/gallon exemption from state gas tax for alcohol fuels until July 1, 1992.

Industrial development bonds for hydro projects issued at option of local governments.

Other Incentives: 6 1/2¢ per kWh buy-back rate for hydro and residential and commercial wind systems.

Solar access laws for passive solar designs.

KANSAS

State Corporation Commission
Research and Energy Analysis Division
4th Floor, State Office Building
Topeka, KS 66612
(913) 532-6026
Contact: Doug Walter

Tax Credits: Residential--30%, up to $1,500 maximum credit, for solar, passive solar design and wind. Scheduled to expire December 31, 1985.

Business--30%, up to a maximum credit of $4,500, for solar and wind. Scheduled to expire December 31, 1985.

Other Tax Incentives: 7¢/gallon exemption from state gas tax for gasoline containing ethanol. Exemption decreases to 3¢/gallon on July 1, 1986 and 2¢/gallon on July 1, 1987.

Other Incentives: None.

APPENDIX I

KENTUCKY

Division of Alternate Energy
Kentucky Energy Cabinet
P.O. Box 11888, Iron Works Pike
Lexington, KY 40578
Contact: John Stapleton

Tax Credits: Residential--15% credit, to a maximum of $1500, for solar, passive solar design, geothermal and wind. All systems must meet state standards. Multi-purpose components for passive solar design eligible for tax credit. Expires December 31, 1986.

Business--15% credit, to a maximum of $1500, for solar, geothermal, and wind. All systems must meet state standards. Cost of multi-purpose components for passive solar design eligible for tax credit. Expires December 31, 1986.

Other Tax Incentives: Property tax exemption for alcohol fuel systems. Equipment for producing alcohol fuels are exempt from sales tax.

Alcohol fuels exempt from state gas tax.

Other Incentives: Loans from the Kentucky Development Finance Authority available for qualifying alcohol fuel projects.

LOUISIANA

Department of Natural Resources
Energy, Research, and Planning Division
P.O. Box 44156
Baton Rouge, LA 70804
(504) 342-5361
Contact: Paul Adams

Tax Credits: None.

Other Tax Incentives:	Ten year exemption from property tax can be applied to industrial buildings, machinery and equipment associated with commercial solar, commercial biomass, refuse-to-energy, alcohol fuels, commercial geothermal, ocean, and commercial wind systems. All state and most local taxes can be waived on construction materials and operating equipment in specially designated Enterprise Zones for commercial solar, commercial biomass, refuse-to-energy, alcohol fuels, commercial geothermal, ocean, and commercial wind systems. Residential solar systems and passive solar designs are exempt from property taxes.
Other Incentives:	None.

MAINE

Office of Energy Resources
55 Capitol St.
Augusta, ME 04330
(207) 289-3811
Contact: Nancy Holmes

Tax Credits:	Residential--20% for solar systems, limited to a maximum credit of $300, and 20% for wind systems, up to a maximum credit of $100. Expires December 31, 1988. Business--none.
Other Tax Incentives:	Property tax exemption for alcohol fuel systems at option of local governments. Property tax exemption for hydro and wind systems at option of local governments. Industrial development bonds available for refuse-to-energy systems. Use of industrial development bonds for hydro systems at option of local governments.
Other Incentives:	Grants available for qualifying refuse-to-energy systems.

APPENDIX I

MARYLAND

903 State Office Bldg.
301 West Preston St.
Baltimore, MD 21201
(301) 383-6810
Contact: Donald E. Milsten

Tax Credits: None.

Other Tax Incentives: Property tax exemption for residential solar systems at option of local governments.

Other Incentives: Loans available for commercial solar projects.

MASSACHUSETTS

Executive Office of Energy Resources
Solar Office, Room 1500
100 Cambridge St.
Boston, MA 02202
(617) 727-4732
Contact: Mark A. Roberts

Tax Credits: Residential--35%, to a maximum credit of $1000, for solar, passive solar design, and wind. Scheduled to expire December 31, 1985. Dual purpose components in passive solar design ineligible for credit.

Business--35% for wind, to a maximum credit of $1000. Scheduled to expire December 31, 1985.

Other Tax Incentives: Property tax exemption for residential solar and wind systems.

Commercial solar and wind systems are exempt from excise and property taxes for 20 years.

Sales tax exemption for residential solar, biomass, and geothermal systems and commercial and residential wind systems. For residential biomass systems, sales tax exemption only applies to wood-fueled central heating systems costing over $900.

Hydro systems exempt from real estate taxes for 20 years if constructed after January 1, 1979.

Other Incentives: Grants for commercial biomass projects, up to a maximum of $5,000.

APPENDIX I

MICHIGAN

Energy Administration
Michigan Department of Commerce
P.O. Box 30228
Lansing, MI 48909
(517) 373-0480
Contact: Tom Stanton or Jeff Pillon

Tax Credits:	Residential--30% of the first $2,000 and 15% of the next $3,000 for single-family residences owning a solar or wind system or a passive solar design. For multi-family dwellings, the credit is 30% of the first $2,000 and 15% of the next $7,000 for qualifying solar and wind systems. Residential biomass systems allowed if backing up qualified solar or wind systems. Expires December 31, 1988. Business--None.
Other Tax Incentives:	1¢/gallon exemption for alcohol fuels. Scheduled to expire December 31, 1985.
Other Incentives:	Favorable building codes for solar at the option of local governments.

MINNESOTA

State Energy Division
900 American Center Bldg.
St. Paul, MN 55101
(612) 297-4008
Contact: Paul Helgeson

Tax Credits:	Residential--20%, to a maximum credit of $2,000 for solar, passive solar design, and wind. Scheduled to expire December 31, 1985. Business--none.
Other Tax Incentives:	4¢/gallon credit for alcohol fuels. Hydro eligible for industrial development bonds.
Other Incentives:	Solar access at option of local governments. Loans available for commercial biomass projects. Favorable building codes for passive solar designs.

MISSISSIPPI

Department of Energy and Transportation
Office of Energy
510 George St.
Jackson, MS 39202
(601) 961-4733
Contact: Diane Anderson or P.T. Bankston

Tax Credits: None.

Other Tax Incentives: State colleges, universities, and junior colleges that purchase a solar system are exempt from paying sales tax.

Other Incentives: Funds for feasibility studies of commercial biomass and refuse-to-energy projects provided on a matching basis.

Favorable building codes for passive solar designs at the option of local governments.

MISSOURI

Department of Natural Resources
Solar Section, Division of Energy
P.O. Box 176
Jefferson City, MO 65102
(314) 751-4000
Contact: Steve Hencey

Tax Credits: None.

Other Tax Incentives: None.

Other Incentives: Solar access for passive solar design.

APPENDIX I

MONTANA

Department of Natural Resources and Conservation
Energy Division
32 South Ewing
Helena, Montana 59620
(406) 444-6696
Contact: Greg Mills

Tax Credits:	Residential--5% of the first $1,000 and 2.5% of the next $3,000 to a maximum credit of $125 for solar, wind, passive solar design, biomass, geothermal, and hydro. Dual purpose components for passive solar ineligible for credit. Expires December 31, 1986.
	Business--35% of taxable or net income for wind systems, if $5,000 or more is spent. Federal state credits combined cannot exceed 60% of total project cost. No expiration date. Refuse-to-energy systems are eligible for a 5% credit on the first $1,000 and 2.5% on the next $3,000 until December 31, 1986.
Other Tax Incentives:	Solar, biomass, geothermal, hydro, and wind systems are exempt from property taxes for 10 years, up to $20,000 of the system's appraised value for single family residences and $100,000 for multi-family or nonresidential structures. If commercial wind tax credit is claimed, system is not eligible for property tax exemption.
	For systems producing alcohol fuel, property tax is levied only at 3% of assessed value for the first 10 years.
Other Incentives:	Loans for commercial solar, commercial biomass, hydro, and refuse-to-energy systems available through Renewable Energy and Conservation Program.
	Alcohol fuel producers receive 50¢/gallon subsidy. Decreased to 30¢/gallon in April 1986; terminates April 1, 1989.

APPENDIX I

NEBRASKA

Energy Office
Box 95085
Lincoln, NB 68509
(402) 471-2867
Contact: Denise Disney

Tax Credits: Residential--15%, to a maximum credit of $1500, for solar, passive solar design, and wind. Credit is reduced to 10% in 1986. Expires December 31, 1986.

Business--15%, to a maximum credit of $1500 for individuals and $3000 for corporations, for solar and wind. Does not include solar thermal power systems. Credit is reduced to 10% in 1986. Expires December 31, 1986.

Other Tax Incentives: 3¢/gallon gas tax exemption for alcohol fuels.

Other Incentives: Solar access at option of local governments.

NEVADA

Office of Community Services
1100 E. Williams
Carson City, NV 89710
(702) 885-4420
Contact: Curtis Framel

Tax Credits: None.

Other Tax Incentives: Residential biomass, commercial and residential geothermal, commercial hydro, and commercial wind, and alcohol fuel systems exempt from property taxes.

Other Incentives: None.

NEW HAMPSHIRE

Governor's Energy Office
2 1/2 Beacon St.
Concord, NH 03301
(603) 271-2711
Contact: Dennis Herbert or Joyce Kilens

Tax Credits: None.

Tax Incentives: Residential solar, commercial and residential wind and residential biomass systems are exempt from property taxes at the option of local governments.

Owners of small hydro system can pay local governments directly 2 1/2-5% of the facility's gross revenues in lieu of taxes.

Commercial, electricity-producing biomass systems eligible to be taxed at the utility rate, rather than at the normal business rate.

Other Incentives: Structures solely heated by a renewable energy source exempt from complying with the state energy code.

NEW JERSEY

Department of Energy
Alternative Technology Unit
101 Commerce St.
Newark, NJ 07102
(201) 648-4914
Contact: Richard Brandt

Tax Credits: None.

Tax Incentives: Property and sales tax exemption for residential solar and residential and commmercial wind systems.

Other Incentives: Favorable building codes and solar access for passive solar design at option of local governments.

APPENDIX I

NEW MEXICO

Resource Management Division
New Mexico Energy and Minerals Department
525 Camino de los Marquez
Santa Fe, NM 87501
(505) 827-5908
Contact: Charles Wood

Tax Credits: Residential--25%, up to a maximum credit of $4,000, for solar, wind and passive solar design. Scheduled to expire December 31, 1985. Solar-powered irrigation systems are also eligible up to a maximum credit of $25,000; this credit expires December 31, 1986. Geothermal systems are eligible for a 20% tax credit. Beginning in 1987, the credit decreases 5% each year until expiring December 31, 1989. Maximum credit of $60,000.

Business--25% for solar and wind, up to a maximum expenditure of $4,000. Scheduled to expire December 31, 1985. Geothermal systems are eligible for a 20% credit. Beginning in 1987, the credit decreases 5% each year until expiring December 31, 1989. No known maximum credit for geothermal systems.

Other Tax Incentives: Ethanol systems exempt from gross receipts tax.

Industrial development bonds can be issued for hydro projects.

Investment credits available for geothermal systems.

Other Incentives: Favorable building codes and solar access for passive solar design.

Grants available for demonstration hydro projects.

Matching grants available for geothermal well drilling.

APPENDIX I

NEW YORK

State Energy Office
Empire State Plaza
Albany, NY 12223
(518) 465-6251
Contact: Barry Liebowitz

Tax Credits: Residential--55% (including federal credit) of the cost of a solar or wind system or a passive solar design, or $6,750 (including $4,000 federal credit), whichever is less. Scheduled to expire December 31, 1985.

Business--none.

Other Tax Incentives: Residential solar, commercial and residential wind systems, and passive solar designs are exempt from property taxes.

Property tax exemptions for commercial geothermal systems at the option of local governments.

Use of industrial development bonds for hydro projects at option of local governments.

Other Incentives: Licensing and permitting incentives for the development of small hydro.

Power generated from small hydro and wind systems must be purchased for no less than 6¢/kWh.

APPENDIX I

NORTH CAROLINA

Department of Commerce
Energy Division
P.O. Box 25249
Raleigh, NC 27611
(919) 733-2230
Contact: None Given

Tax Credits: Residential--Solar heating and cooling systems and passive solar designs are eligible for a 25% credit, up to a maximum of $1,000. Solar industrial process heat and ethanol systems are eligible for a 20% credit, up to a maximum of $8,000 for solar industrial process heat systems. No maximum allowable credit is given for ethanol systems. Wood boiler systems are eligible for a 15% credit, also with no maximum credit. For wind, methanol, and hydro systems, a 10% credit is available, up to a maximum of $1,000, $2,500, and $5,000, respectively. There is no expiration date for any of these credits.

Business--Same as residential, except photovoltaic system owners are eligible for a 20% credit with no ceiling. There is no expiration date.

Other Tax Incentives: Solar heating and cooling systems, excluding solar hot water systems, are assessed at the same value as conventional heating and cooling systems.

Other Incentives: Grants and loans available for solar, biomass, and wind projects.

NORTH DAKOTA

Renewable Energy Program
Office of Intergovernmental Assistance
State Capitol, 14th Floor
Bismark, ND 58505
(701) 224-2290
Contact: Mike Mahlum

Tax Credits: Residential--15% (5% for 3 years) for solar, passive solar design, geothermal, and wind. No maximum credit. No minimum temperature required for geothermal. No expiration date.

Business--15% (5% for 3 years) for solar, geothermal, and wind. No maximum credit. No expiration date.

Other Tax Incentives: Gas tax exemption for alcohol fuels.

Residential solar and commercial and residential geothermal and wind systems exempt from property taxes.

Other Incentives: None.

NORTHERN MARIANAS

Office of Energy
NAURU Building, 5th Floor
Saipan, Mariana Islands 96950
(885) 099-7174
Contact: Elizabeth Siudins

Tax Credits: None.

Other Tax Incentives: None.

Other Incentives: Loans available for commercial biomass projects.

OHIO

Department of Development
Community Development Division
Office of Energy Conservation
P.O. Box 1001
Columbus, OH 43266
(614) 466-1805
Contact: Claude W. Eggleton

Tax Credits: Residential--10%, up to a maximum credit of $1,000, for solar, passive solar, geothermal, and wind (including mechanical wind systems). Scheduled to expire December 31, 1985. Dual purpose components in passive solar designs not eligible for credit.

Business--10%, for solar, geothermal, and wind. No maximum credit. Scheduled to expire December 31, 1985.

Other Tax Incentives: Residential solar, commercial biomass, refuse-to-energy, and commercial and residential geothermal and wind systems exempt from property and sales taxes.

Alcohol fuels produced from grain or wood has 2.5¢/gallon gas tax exemption. Methanol not included. Maximum exemption allowed, including federal exemption, is 8.5¢/gallon.

Other Incentives: Favorable building codes and solar access for passive solar design at the option of local governments.

OKLAHOMA

Corporation Commission
Energy Conservation Services Division
4400 N. Lincoln Blvd.
Suite 251
Oklahoma City, OK 73105
(405) 521-3941
Contact: Steven Boggs

Tax Credits: Residential--35%, up to a maximum credit of $3,500, for solar, passive solar design, and wind. Dual purpose components of a passive solar design not eligible for credit. Scheduled to expire December 31, 1990. The state credit increases to 55% in 1986 if the federal credits are not renewed and declines 5% each year until expiring in 1990.

Business--30%, no maximum, for solar and wind. Expires December 31, 1990. Third party financing ruled ineligible for tax credits by state tax commission.

Other Tax Incentives: None.

Other Incentives: None.

APPENDIX I

OREGON

Department of Energy
625 Marion St. NE
Salem, OR 97310
(503) 378-8446
Contacts: Nancy Rockwell, Michael Grainey, and Larry Gray

Tax Credits: Residential--25%, to a maximum credit of $1,000 through 1985, $500 through 1986, and $250 through 1988, for solar, passive solar design, geothermal and wind. 50% and 10% minimum energy contribution required from solar heating and cooling systems and passive solar designs, respectively. On-site resource measurements are required for wind systems. Mechanical wind systems eligible for credit. Expires December 31, 1989.

Business--35% for solar, biomass, geothermal, hydro, and wind. No ceiling, but credit is spread over 5 years, with 10% allowed the first year, 10% the second year, and 5% the next three years. Minimum contribution of 10% required from solar and geothermal systems. One year on-site resource measurements required for wind systems. Scheduled to expire December 31, 1985.

Other Tax Incentives: Residential solar and commercial and residential geothermal and wind systems exempt from property taxes.

Other Incentives: Solar, biomass, refuse-to-energy, alcohol fuels, geothermal, hydro, and ocean systems eligible for Small Scale Energy Loan Program. If loan is obtained, the tax credit cannot be taken.

PENNSYLVANIA

Governor's Energy Council
P.O. Box 8010
Harrisburg, PA 17105
(717) 783-9981
Contact: Roger Clark

Tax Credits: None.

Other Tax Incentives: None.

Other Incentives: Feasibility grants for biomass projects.

APPENDIX I

PUERTO RICO

Survey not returned.

RHODE ISLAND

Governor's Energy Office
72 Orange St.
Providence, RI 02903
(401) 277-3371
Contact: Rob Ericson

Tax Credits:	Residential--10%, up to a maximum credit of $1,000, for solar, passive solar design, and wind. Credits for passive solar designs and solar systems expire June 30, 1990; no expiration date for wind systems. Business--10% for solar, wind, and hydro. No known maximum credit. No expiration for hydro and wind; solar credits expire June 30, 1990.
Other Tax Incentive:	Residential solar and wind systems are assessed at no more than the value of conventional energy system capacity that is being displaced. In most cases, this means residential solar and wind systems are exempt from property taxes. Sales tax rebate available for residential solar and wind systems. Partial property tax exemption for hydro systems. industrial development bonds available for hydro systems if it can be shown that system will be a significant job creator.
Other Incentives:	Purchase of solar easements legally recognized.

SOUTH CAROLINA

Governor's Office
Division of Energy Policy
1205 Pendleton St. #441
Columbia, SC 29201
(803) 758-7874
Contact: Suzanne Rhodes

Tax Credits:	Residential--25%, up to a maximum credit of $1,000, for solar, passive solar design, biomass, geothermal, and wind. No expiration date. Business--25%, up to a maximum credit of $1,000, for solar, biomass, refuse-to-energy, geothermal, hydro, and wind. No expiration date.
Other Tax Incentives:	None.
Other Incentives:	None.

SOUTH DAKOTA

Office of Energy Policy
Capitol
Pierre, SD 57501
(605) 773-3603
Contact: Steven Wegman

Tax Credits:	None.
Other Tax Incentives:	Residential solar, biomass, and commercial and residential geothermal and wind systems exempt from property taxes. 3¢/gallon exemption from state gasoline tax for alcohol fuels. Use of industrial development bonds for hydro systems at the option of local governments.
Other Incentives:	Favorable building codes for passive solar designs.

APPENDIX I

TENNESSEE

Department of Economic and Community Development
Energy Division
320 6th Ave. N.
6th Floor
Nashville, TN 37219
(615) 741-6671
Contacts: Brian Hensley and Jimmy Johnston

Tax Credits: None.

Other Tax Incentives: 4¢/gallon exemption from state gasoline tax for gasoline containing at least 10% ethanol.

Other Incentives: Some grants given for biomass projects.

TEXAS

Energy Efficiency Division
Public Utility Commission of Texas
7800 Shoal Creek Blvd., Suite 400N
Austin, TX 78757
(512) 458-0312
Contact: Judy Rogers

Tax Credits: None.

Other Tax Incentives: Franchise tax exemption for businesses involved exclusively in the sale, manufacture, or installation of solar, biomass, refuse-to-energy, geothermal, hydro, ocean, and wind systems.

A business is eligible for a reduction in franchise taxes if it uses solar, biomass, or geothermal systems to meet heating, cooling, or other energy needs.

Residential solar, biomass, commercial and residential geothermal and wind, ocean, alcohol fuel, and refuse-to-energy systems are exempt from the state sales tax.

Alcohol fuel systems are exempt from property taxes if end product is used on-site.

Other Incentives: Favorable building codes and solar access for passive solar designs at the option of local governments.

APPENDIX I

UTAH

Energy Office
355 West North Temple
3 Triad Center, Suite 450
Salt Lake City, UT 84180
(801) 538-5428
Contacts: Denise Beaudoin or Scott Guttim

Tax Credits:	Residential--25%, up to a maximum credit of $1,500, for solar and wind. Passive solar designs eligible for a 10% credit up to $1,500. Expires December 31, 1990. Business--10%, up to a maximum credit of $25,000, for solar, biomass, refuse-to-energy, hydro, and wind. Expires December 31, 1990.
Other Tax Incentives:	Property tax exemption for alcohol fuel systems at the option of local governments. Use of industrial development bonds for hydro systems at the option of local governments. Qualified alcohol production facilities allowed a depletion allowance from the state corporate franchise tax.
Other Incentives:	A subsidy of 30¢/gallon provided to in-state alcohol production facilities. State law allowing solar easement. Solar access offered by some local governments.

VERMONT

Survey not returned

APPENDIX I

VIRGINIA

Department of Mines, Minerals and Energy
The Bookbindery Bldg.
2201 W. Broad St.
Richmond, VA 23220
(804) 257-6883
Contact: Diane Killpack

Tax Credits:	Residential--20%, up to a maximum of $1,000, for solar and wind systems and passive solar designs. Decreases to 10% in 1986. Expires December 31, 1986. Business--Same as residential, but passive solar designs are ineligible.
Other Tax Incentives:	Property tax exemption for solar systems at the option of local governments.
Other Incentives:	Grant and loan program for the purchase and installation of solar systems in schools and hospitals.

WASHINGTON

State Energy Office
400 E. Union, First Floor, ER-11
Olympia, WA 98504
(206) 586-5000
Contact: Jim Kerstetter

Tax Credits:	None.
Other Tax Incentives:	2.8¢/gallon state gasoline tax exemption for alcohol fuels. Equipment that produces alcohol fuels exempt from property tax. Utilities can deduct from utility taxes cost of renewable energy that produces natural gas or electricity. Industrial development bonds can be used for refuse-to-energy facilities.
Other Incentives:	Loans and grants available for refuse-to-energy facilities.

APPENDIX I

WEST VIRGINIA

Fuel and Energy Office
1426 Kanawha Blvd., East
Charleston, WV 25301
(304) 348-8860
Contact: John F. Herholdt Jr.

Tax Credits:	None.
Other Tax Incentives:	None.
Other Incentives:	None.

WISCONSIN

Division of State Energy
Department of Administration
P.O. Box 7868
Madison, WI 53707
(608) 266-7615
Contact: Mary Massey

Tax Credits:	Residential--10% direct refund, up to $750, for solar, passive solar design, and wind. Scheduled to expire December 31, 1985. Pool heating systems not eligible. Business--10% direct refund, up to $750 for small businesses and $10,000 for corporations, for solar and wind systems. Scheduled to expire December 31, 1985. Pool heating systems not eligible.
Other Tax Incentives:	Residential solar and commercial and residential and commercial wind systems exempt from property taxes. Use of industrial development bonds for hydro systems at the option of local governments.
Other Incentives:	Feasibility study grants available for refuse-to-energy facilities, up to $50,000, or 50% of the cost of the study. Solar access for passive solar designs at the option of local governments.

APPENDIX I

WYOMING

Energy Conservation Office
Capitol Hill Office Bldg.
25th and Pioneer
Cheyenne, WY 82002
(307) 777-7131
Contact: Gary Garber

Tax Credits:	None.
Other Tax Incentives:	None.
Other Incentives:	None.

APPENDIX II

Renewable Energy Periodicals

BIOMASS/RENEWABLE FUELS

Acres U.S.A.
Acres U.S.A.
P. O. Box 9547
Kansas City, MO 64133
816/737-0064
Monthly
1 year $13

Agribusiness Report
G,V, Olsen Associates
170 Broadway
New York, NY 10038
Monthly
1 year $120

Alcohol Outlook
Information Resources, Inc.
499 S. CapitolStreet, #406
Washington, DC 20003
202/554-0614
Monthly
1 year $375

Alcohol Update
Information Resources, Inc
499 South Capitol St., SW, #406
Washington, DC 20003
202/554-0614
Weekly
1 year $375

Alcohol Week
Inside Washington Publishers
P. O. Box 7167
Washington, DC 20044
Weekly
1 year $375

Bioenergy Bulletin
Bonneville Power Admin./DOE
P. O. Box 3621
Portland, OR 97208
Bimonthly
Free

Bio-Joule
Biomass Energy Institute
1329 Niakwa Road, East
Winnipeg, Manitoba
CANADA R2J 3T4
204/257-3891
Bimonthly
1 year ($20 sub., $25 mbr.)

Biologue
National Wood Energy Association
P. O. Box 4548
Portsmouth, NH 03801
603/436-1921
Eight times /year
Members only

Biomass
Elsner Applied Science Pub.
Crown house
Linton Road
Barking, Essex 1G11 8JU
ENGLAND
1 year $265

Biomass Energy (Abstracts)
G.V. Olsen Associates
170 Broadway
New York, NY 10038
Monthly
Pricing N/A

Bioprocessing Technology
Technical Insights,Inc.
P. O. Box 1304
Fort Lee, NJ 07024
201/568-4744
Monthly
1 year $244/$280

Resource Recovery Report
Frank McManus Publishers
5313 38th Street, NW
Washington, DC 20015
202/362-6034
Monthly
1 year $83

WHA Reporter
Wood Heating Alliance
1101 Connecticut Avenue, NW, #700
Washington, DC 20036
202/857-1181
Bimonthly
Members only

Wood'n Energy
Energy Publications
P. O. Box 2008
Lanconia, NH 03247
Monthly
1 year $24

READS
Biomass Energy Institute
1329 Niakwa Road, East
Winnipeg, Manitoba
CANADA R2J 3T4
203/257-3891
Monthly
1 year $100

GEOTHERMAL

Geothermal Energy
Geothermal World
5762 Firebird Court
Carmarillo, CA 93010
805/482-6288
Monthly
1 year $50

Geothermal Report
Geothermal Report
P. O. Box 35-K
Tracey's Landing, MD 20779
301/261-5010
Twice per month
1 year $155

Geothermal Energy Technology
National Tech. Info. Service
Springfield, VA 22161
PB84-914700
Monthly
1 year $40 (domestic)
1 year $80 (outside U.S.)

Geothermics
Pergamon Press, Inc.
Fairview Park
Elmsford, NY 10523
Quarterly
1 year $70

HYDROPOWER

Hydro Review
Hydro Consultants, Inc.
755 Boylston St., #707
Boston, MA 02116
617/266-3720
Quarterly
1 year $44

Hydrowire
Hydro Consultants, Inc.
755 Boylston St., #707
Boston, MA 02116
617/3720
Biweekly
1 year $275

NHA Membership Update
National Hydropower Association
1017-A King Street
Alexandria, VA 22314
703/683-7783
Weekly
Members only

Water Power and Dam Construction
Business Press International Ltd.
Quadrant House, The Quadrant
Sutton, Surrey SM2 5AS
ENGLAND
Monthly
1 year $110

OCEAN ENERGY

Ocean Industry
Gulf Publishing Co.
P. O. Box 2608
Houston, TX 77001
713/529-4301
Monthly
1 year $15

Oceanus
Woods Hole Oceanographic Institute
Woods Hole, MA 02543
617/548-1400
Quarterly
1 year $20

PHOTOVOLTAICS

Photovoltaic Insider's Report
Photovoltaic Insider's Report
1011 W. Colorado Blvd.
Dallas, TX 75208
214/943-4132
Monthly
1 year $110

Photovoltaics International
PVI Publishing, Inc.
2250 North 16th St., #103
Phoenix, AZ 85006
602/253-9119
Bimonthly
Free to qualified subscribers

Photovoltaics: Solar Electric Magazine
Fore Publishers, Inc.
P. O. Box 3269
Scottsdale, AZ 85257
Bimonthly
1 year $38

PV News
PV Energy Systems, Inc.
Cassanova, VA
703/780-9236
Monthly
1 year $60

SOLAR

New Shelter
Rodale Press, Inc.
33 E. Minor Street
Emmaus, PA 18049
215/967-5171
Nine times a year
1 year $11

Passive Solar Journal
Los Alamos National Labs
Mail Stop J577
Los Alamos, NM 87545
505/667-6441
Quarterly
1 year $80

Progressive Architecture
Subscription Dept.
P. O. Box 95759
Cleveland, OH 44101
Monthly
1 year $18

SEIA News
Solar Energy Industries Association
1717 Massachusetts Avenue, NW, #503
Washington, DC 20036
202/483-6225
Monthly
Members only

Solar Energy Report
CA Solar Energy Industries Assn.
2015 J Street, Suite 14
Sacramento, CA 95814
Monthly
1 year $20 (nonmember)

SUNDEX
Energy Investment Research, Inc.
P. O. Box 73 , Glenville Station
Greenwich, CT 06830
914/937-5167
Monthly
1 year 130, 6 months $75

WIND

Wind Industry News Digest
Alternative Sources of Energy, Inc.
107 S. Central Avenue
Milaca, MN 56353
612/983-6892
Twice Monthly
1 year $54

Wind Engineering and
Industrial Aerodynamics
Elsevier Scientific Publishing Co.
P. O. Box 211
1000 AE Amsterdam
THE NETHERLANDS
Varies
1 year $162

Wind Power Digest
Wind Power Publishing Co.
P. O. Box 700
Bascom, OH 44809
Quarterly
1 year $12

Windirections
British Wind Energy Association
4 Hamilton Place
London, W1V OBQ
United Kingdom

Wind Energy Magazine
Source Communications, Inc.
P. O. A
Del Mar, CA 92014
Quarterly
1 year $12

Wind Engineering
Multi Science Publishing
42/45 New Broad Street
Longon EC2M 1QY
ENGLAND
Quarterly
1 year 50 pounds

World Wind
44A Clarey Avenue
Ottawa, CANADA K1S 2R7
613/233-9732
Monthly

COGENERATION

Cogeneration Action Newsletter
Cogeneration Coalition, Inc.
1819 L Street, NW
Washington, DC 20036
202/887-5200
Monthly
Members only

Cogeneration Report
McGraw-Hill, Inc.
1221 Avenue of the Americas
New York, NW 10020
Bimonthly

Cogeneration World
International Cogeneration Society
1111 19th Street, NW, #1075
Washington, DC 20036
202/659-1552
Bimonthly
1 year $36

Cogeneration Pricing Report
Resource Dynamics Corp.
1349 Chain Bridge Road
McLean, VA
703/356-1300
Monthly
1 year $115

CONSERVATION

Earth Shelter Living
Webco Publishing Co.
110 S. Greeley Street
Spillwater, MN 55082
612/430-1113
Bimonthly
1 year $18

Energy Conservation Bulletin
Energy Conservation Coalition
1001 Connecticut Ave., NW, #535
Washington, DC 20036
202/466-5045
Bimonthly
1 year $25

Energy Design Update: Monthly Newsletter
on Energy Efficient Housing
Cahrers Publications
P. O. Box 716
Boston, MA 02117
Monthly
1 year $107

NAESCO News
National Assn. of Energy Serv. Cos.
2300 M Street, NW
Washington, DC 20037
202/955-9795
Monthly
Members only

RENEWABLE ENERGY (general)

Alternative Energy Retailer
Zackin Publications, Inc.
P.O. Box 2180
Waterbury, CT 06722
203/755-0158
Monthly
1 year $24

Alternative Source of Energy
Alternative Sources of Energy, Inc.
107 S. Central Avenue
Milaca, MN 56353
612/983-6892
Bimonthly
1 year $19.50

Independent Energy (Newsletter)
Indep. Energy Producers Assn.
1001 G Street, #103
Sacramento, CA 95814
916/448-9499
Monthly
Members only

National Energy Journal
National Wood Stove & Fireplace Journal
21640 N. 19th Avenue, Suite C-3
Phoenix, AZ 85027
Monthly
1 year $55

RERIC News/Renewable Energy Review Journal
Renewable Energy Resour. Infor. Center
Asian Institute of Technology
P. O. Box 2754
Bankok, THAILAND
Monthly
Members only

Energy Conservation News
Business Communications Co., Inc.
P. O. Box 2070C
Stamford, CT 06906
203/325-2208
Monthly
1 year $215

Helios (Newsletter)
Dept. of Mechnical Engineering & Energy
University College
Newport Road
Cardiff CF2 1TA

Daylighting Network of America
DNNA News
125 Alumni Hall
Miami University
Oxford, OH 45056
Quarterly
1 year $20

Solar Age
Solar Vision, Inc.
7 Church Hill
Harrisville, NH 03450
603/827-3347
Monthly
1 year $28

Solar Energy
International Solar Energy Society
P. O. Box 52, Parkville
Victoria, Australia 3052
Monthly
1 year $200 (nonmembers)

Solar Energy Intelligence Report
Business Publishers, Inc.
951 Pershing Drive
Silver Spring, MD 20910
301/587-6300
Weekly
1 year $185

Solar Industry Bulletin
Solar Vision, Inc.
7 Church Hill
Harrisville, NH 03450
603/827-3347
Twice monthly
1 year $245

Solar Political Report
Solar Lobby
1001 Connecticut Ave., NW, #638
Washington, DC 20036
202/466-6350
Published as needed
Members only

Solar Utilization News (SUN)
Alternative Energy Institute
P. O. Box 3100
Estes Park, CO 80517
monthly
1 year $15

Sun Times Newsletter
Solar Lobby
1001 Connecticut Ave., NW, #638
Washington, DC 20036
202/466-6350
Bimonthly
1 year $20 membership fee

Sunworld
International Solar Energy Society
P. O. Box 26
Highette, Victoria 3190 Australia
Bimonthly
1 year $40 (nonmembers)

Solar Thermal Energy Technology
National Technical Info. Service
5285 Port Royal Road
Springfield, VA 22161
703/487-4630
Semi-monthly
1 year $40

World Solar Markets
Business Publishers, Inc.
951 Pershing Drive
Silver Spring, MD 20910
301/587-6300
Monthly
1 year $250

ENERGY GENERAL (with renewable ref.)

City Currents
United States Conference of Mayors
1620 Eye Street, NW
Washington, DC 20006
Varies per publication

Electric Light & Power
Dun Donnelly Publishing CO.
P. O. Box 1030
Barrington, IL 60010
312/381-1840
Monthly
1 year per certificate.

Energy Conversion and Management
Pergamon Press, Inc.
Fairview Park
Elmsford, NY 10523
Quarterly
1 year #150

Energy Daily
King Publishing Group
915 15th Street, NW
Washington, DC 20005
202/638-4260
Five times/week
1 year $895

Energy Management
Association of Energy Engineers
1111 Chester Avenue
Cleveland, OH 44114
Monthly except July and December
1 year $30

Energy Planning Network
APA Energy Planning Division
6800 Granby Street
Bethesda, MD 20817
Quarterly
1 year $30 (nonmember)

Energy: The International Journal
Pergamon Press, Inc.
Fairview Park
Elmsford, NY 10523
Monthly
1 year $280

Energy User News
Fairchild Publications
7 E. 12th Street
New York, NY 10003
201/356-7773
Weekly
1 year $42

Energy Users Report
Bureau of National Affairs
1231 25th Street, NW
Washington, DC 20037
202/452-4200
Weekly
1 year $472

Environment and Energy Study
Institute Weekly Bulletin
Envir. and Energy Study Inst.
218 D Street, SE
Washington, DC 20003
202/546-3200
Weekly
1 year $275

EPRI Journal
Electric Power Research Inst.
P.O. Box 101412
Palo Alto, CA 94303
415/855-2730
10 times/year
Free

Gas Turbine World
Peqot Publishing Inc.
654 Hillside Road
Fairfield, CT 06430
Bimonthly
1 year $40

Journal of Energy Resource Technology
Amer. Soc. of Mech. Engineers
P.O. Box 3199
Grand Central Station
Monthly
1 year $72 (nonmembers)

Monitor
Federal Energy Reg. Com.
Division of Public Information
825 North Captiol Street, NE
Washinghton, DC 20426
202/357-8380
Biweekly
1 year $39

PUR Executive Information Service
Public Utilities Reports, Inc.
1700 N. Moore Street, #2100
Arlington, VA 22209
703/243-7000
Weekly
1 year $195

International Power Generation
Industrial & Marine Publications Ltd.
2 Queensway, Redhill
Surrey, RH1 1QS, ENGLAND
10 issues/year
1 year $71

The Forum
The Forum for Applied
Reseach & Publc Policy
Tennessee Valley Authority
400 Summit Hill Drive, E3C85
Knoxville, TN 37920
615/632-8019

Public Power
American Public Power Association
2301 M Street, NW
Washington, DC 20037
202/775-8300
Bimonthly
1 year $25

Public Utilities Fortnightly
Public Utilities Reports, Inc.
1700 North Moore Street, #2100
Arlington, VA 22209
703/243-7000
Biweekly
1 year $72

Western Energy Update
Western Interstate Enewrgy Board/WINB
Stapleton Plaza, #6500
3333 Quebec Street
Denver, CO 80207
Weekly
1 year $145

PURPA Lines
Hydro Consultants, Inc.
755 Boylston Street, #707
Boston, MA 02116
617/266-3720
Biweekly
1 year $275

Power
Subscription Department
P. O. Box 2031
Mahopac, NY 10541
Monthly
1 year $14

Builders
National Assoc. of Homebuilders
Special Solar Reprint
15th & M Street, NW
Washington, DC 20005
Monthly
$1.50 each

Gasahol, U.S.A.
P. O. Box 9547
Kansas City, MO 64133
816/737-0064
Monthly
1 year $13

Powerline
Environmental Action Foundation
724 Dupont Circle
Washington, DC 20036
1 year $25

Rural Electrification
National Rural Electric Coop. Assn.
1800 Massachusetts Avenue, NW
Washington, DC 20036
Monthly
1 year $16

Critical Mass Bulletin
Public Citizen, Inc.
215 Pennsylvania Avenue, SE
Washington, DC 20003
202/546-4790
1 year $13

APPENDIX III

Renewable Energy Information Sources

RENEWABLE ENERGY ORGANIZATIONS

American Solar Energy Society (ASES)
2030 17th Street
Boulder, CO 80302
303/443-3130

American Wind Energy Assoc. (AWEA)
1017A King Street
Alexandria, VA 22314
703/684-5196

Bio-Energy Council
1815 N. Lynn Street, #200
Arlington, VA 22209
703/276-9411

Biomass Energy Research Assoc. (BERA)
1825 K Street, NW, #298
Washington, DC 20006
202/785-2856

Geothermal Resources Council (GRC)
P. O. Box 1350
Davis, CA 95617
916/758-2360

Independent Energy Producers (IEP)
1001 G Street, #103
Sacramento, CA 95814
916/448-9499

Interstate Solar Coordination
Council (ISCC)
400 State Road 401
Cape Canaveral, FL 32920
305/783-0300

National Hydropower Association
(NHA)
1017A King Street
Alexandria, VA 22314
703/683-7783

U.S. Export Council for Renewable
Energy (U.S. ECRE)
1333 New Hampshire Ave., NW, #400
Washington, DC 20036
202/887-4421

National Wood Energy Association (NWEA)
8400 S. Winn Road, Route 3
Mt. Pleasant, MI 48854
517/866-2650

Ocean Energy Council (OEC)
c/o Gibbs & Cox
1235 Jeff Davis Highway #700
703/979-1240

Passive Solar Industries Council (PSIC)
1414 Prince St.
Alexandria, VA 22314
703/683-5003

Renewable Energy Institute
1001 Connecticut Ave. NW #719
Washington, DC 20036
202/857-1660

Renewable Fuels Association (RFA)
499 South Capitol St., SW, #420
Washington, DC 20003
202/484-9320

Solar Energy Industries Assoc. (SEIA)
1717 Mass. Avenue, NW, #503
Washington, DC 20036
202/483-6225

Solar Lobby
1001 Connecticut Ave., NW, #638
Washington, DC 20036
202/466-6350

Solar Rating and Certification
Council (SRCC)
1001 Connecticut Ave., NW. #800
Washington, DC 20036
202/452-0078

Wood Heating Alliance (WHA)
1101 Connecticut Ave., NW, #700
Washington, DC 20036
202/857-1181

OTHER NATIONAL INFORMATION SOURCES

Air Conditioning & Refrigeration Institute (ARI)
1501 Wilson Blvd., 6th Floor
Arlington, VA 22209
703/524-8800

American Society of Heating Refrigeration, and Air Conditioning Engineers (ASHRAE)
1791 Tullie Circle, NE
Atlanta, GA 30329
404/636-8400

American Public Power Assoc. (APPA)
2301 M Street, NW
Washington, DC 20037
202/775-8300

Argonne National Laboratory
Department of Energy
8700 South Cass Ave.
Argonne, IL 60439
312/972-2000

Batelle Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509/375-2121

Conservation and Renewable Energy Inquiry and Referral Service (CAREIRS)
P. O. Box 8900
Silver Spring, MD 20907
800/523-2929

Edison Electric Institute (EEI)
1111 19th Street, NW
Washington, DC 20036
202/828-7400

Electric Power Research Institute (EPRI)
3412 Hillview Avenue
P. O. Box 10412
Palo Alto, CA 94303
415/855-2000

Energy Information Administration (EIA)
U.S. Department of Energy
1000 Independence Ave. SW
Washington, DC 20585
202/252-5209

Federal Energy Regulatory Commission (FERC)
825 North Capitol Street, NE
Washington, DC 20426
202/357-8055

Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720
415/486-4000

Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, NM 87545
505/667-5061

National Aeronautic and Space Administration (NASA)
Lewis Research Center
2100 Brookpark Rd.
Cleveland, OH 44135
216/433-4000

National Appropriate Technology Assistance Service (NATAS)
U. S. Department of Energy
P. O. Box 2525
Butte, MT 59702
800/428-1718 (MT)
800/428-2525 (other)

National Center for Appropriate Technology (NCAT)
P. O. Box 3838
Butte, MT 59702
406/494-4572

National Rural Electric Cooperative Assoc. (NRECA)
1800 Massachusetts Ave., NW
Washington, DC 20036
202/857-9500

National Technical Information Service (NTIS)
5285 Port Royal Rd.
Springfield, VA 22161
703/487-4600

Sandia National Laboratories (Albuquerque)
P. O. Box 5800
Albuquerque, NM 87185
505/844-5678

Solar Energy Research Institute (SERI)
1617 Cole Boulevard
Golden, CO 80401
303/231-1235

U.S. Department of Energy (DOE)
1000 Independence Avenue, SW
Washington, DC 20585
202/252-5000

Office of Scientific and Technical Information (OSTI)
Dept. of Energy
P. O. Box 62
Oak Ridge, TN 37831
615/576-6837

Sandia National Laboratories (Livermore)
P. O. Box 969
Livermore, CA 94550
415/422-2247

Tennessee Valley Authority (TVA)
308 Power Building
Chattanooga, TN 37401
800/362-9250

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